Department of Agriculture, Madras.

Vol. IV—Bulletin No. 71.

IRRIGATION

BY

R. CECIL WOOD,

Principal, Agricultural College, Coimbatore.

MADRAS:

[PRINT]ED BY THE SUPERINTENDENT, GOVERNMENT PRESS.

1921.

A. 138/1
1/78

Department of Agriculture, Madras.

Vol. IV—Bulletin No. 71.

IRRIGATION

BY

R. CECIL WOOD,

Principal, Agricultural College, Coimbatore.

MADRAS:

REPRINTED BY THE SUPERINTENDENT, GOVERNMENT PRESS.

1920.

PREFACE.

THE following notes are part of the series of general lectures on Agriculture, included in the Short course at the Coimbatore College. It is my intention to write up other sections in the same way, with the idea ultimately of combining them into a text-book.

R. C. WOOD,
Principal, Agricultural College and Research Institute, and Superintendent of Central Farm, Coimbatore.

1917.

THE present issue is a reprint of the original. It must therefore be remembered that the prices quoted do not apply to present conditions.

G. A. D. STUART,
Director of Agriculture.

1920.

A·138)1

IRRIGATION.

THE ARTIFICIAL SUPPLY OF WATER TO CROPS.

1. Importance of water to plants.—The importance of water to all forms of plant life is due not more to the fact that it makes up so large a part by weight of all living and growing parts of plant tissue, than for the reason that it is the medium in which the transformation of crude materials into assimilable food products takes place, as well as the means whereby these products are transported to their destinations at the various places where they are needed. It is thus a matter of the first importance to see that field crops get the right amount of water at the right time and in the right place, and this end is effected either by supplementing the natural rainfall by irrigation, or by reducing the effect of excessive rain by drainage. These two operations must be considered in very close relationship, for though it may seem that in any place where rainfall is deficient, no harm could follow from the artificial use of irrigation water, yet the evil effects of excess of water are so great, especially in the artificial conditions in which agricultural crops are raised, that provision should nearly always be made simultaneously for both processes.

That water is a necessity for the growth of all plant life is then abundantly clear, but before irrigation is adopted it has to be shown that this particular necessity is present in insufficient quantity. The size of any crop is limited by several factors, of which the supply of moisture is only one. The supply of plant food of different kinds is of course another; the habit and character of the plant, the strength of the straw, or the space available for root development may also be quoted as factors which limit crop production. It is probable that in most parts of this country the *dominant* factor under dry or garden conditions is the supply of water to the crop, either directly in the case of dry lands by the quantity of water naturally available, or indirectly as well, in the case of garden lands, by conditions which arise when water is supplied artificially.

Let us take the case of dry land first and see what arguments can be brought to support this view. Practically, of course, it is clear that a very high market value is placed upon the supply of water for agricultural purposes in almost every district, even where it might at first be thought that the rainfall was sufficient. The rates charged for water in the big delta systems are very low, and it is not until we see the sums invested in the digging of wells, and

the ceaseless toil with which their water is lifted and carefully applied to garden crops, that we can realize how valuable this commodity is considered. At Coimbatore, it is estimated that an irrigated crop of *Sorghum* (cholam) will produce 2,000 lb. of grain and 5,000 lb. of straw ; a dry crop averages about 600 lb. of grain and 2,500 lb. of straw: the difference at present prices is about Rs. 70. This is of course not all due to the water, because the garden lands are highly manured, but even making a considerable allowance for this, it is clear that the value of the water is very great. Another proof of the importance of water, and the way in which it limits crop production, may be found in the very high yields which are occasionally recorded in dry fields, without any apparent diminution in their permanent fertility. On the permanent unmanured plot at the Bellary Agricultural Station, the unprecedented yield of 1,066 lb. of 'dry' *Sorghum* was obtained in the season of 1904-05, but there was no sign of undue exhaustion of plant food observable in the succeeding years, and it may be supposed, that though there was sufficient plant food for much bigger crops than were generally obtained, yet owing to insufficiency of moisture, the crop could not make use of it: the moisture was the limiting factor, and the plant could only grow up to the amount available in the soil.

It is of course clear that variation in the soil will have a considerable influence on the actual quantity of water needed in a particular case, and the rate at which it should be supplied, and general though the statement above, viz., that moisture is in the majority of cases the limiting factor, may be, yet undoubtly there are districts where owing to the retentive nature of the soil and the enjoyment of a fair rainfall, the moisture in the soil is sufficient *normally* for the requirements of the crops grown. Still, even in an irrigated crop, it can often be seen that the plants which stand near the channel, where the water runs into the field, grow very big and strong, and stand as a proof that the supply of water is the factor which is keeping the rest of the crop back.

The irrigation of garden land moreover introduces other problems which follow immediately on the artificial supply of water ; questions concerning the proper aeration of the soil, the subsoil, and the roots of the plants, the rise of injurious salts in the land, and other questions which are really connected with drainage. This class of land is merely mentioned to show that following in the train of the great advantages which a water-supply confers, are certain dangers which only careful cultivation will avoid.

There is another consideration and that is the crop grown, and here, though we find practices varying in different districts, a general distinction can be drawn between 'garden' or irrigated and 'dry' or rain-fed crops. We get in the districts of Ganjām, Malabar and South Kanara rain-fed paddy, though paddy is of

course, in the main, a typical irrigated crop. Ragi (*Eleusine coracana*) is a crop just on the border line, being found equally as a rain-fed and an irrigated crop. Sugarcane may be quoted as a crop which under Madras conditions, even in the districts of heaviest rainfall, needs irrigation at some portion of its growth, and indeed many of the most valuable crops of Southern India are grown under 'garden' conditions, so that irrigation will not only increase the yield of the ordinary dry land crops as shown above, but will render possible the cultivation of more profitable crops such as tobacco, turmeric, and betel vine which it would otherwise be impossible to grow.

Since the ultimate source of all water-supply is the rain, any deficiency—and we have endeavoured to show that such deficiency is far from being uncommon—must be due to an insufficient precipitation. This at once provokes the question—What is a sufficient rainfall?—but to this question it is impossible to give an answer. Not only must the total amount of rainfall be considered, but its *concentration*, because it is clear that single heavy falls of rain will not only lead to a considerable waste, in the large quantity of 'run off', i.e., the water which runs of the surface without being absorbed, but will necessarily increase the periods during which no rain falls, and when therefore the moisture in the soil may fall below what is wanted by the plant. When it is further considered that different crops differ very widely in their water requirements, and that different soils vary as widely in their power of absorbing and retaining moisture, it is clear that no definite answer can be given.

Experiments performed in America have shown that under certain conditions from 150 to 300 lb. of water are required for the production of 1 lb. of dry matter: or from 13—26 inches of rain during the crop growth.

2. Sources of water for irrigation.—All the sources of water which may be used for agricultural purposes depend originally upon portions of the rainfall which can be intercepted on their way to the sea or drawn from the supply which is stored in the earth itself. The latter class we may consider first, irrigation from wells being a most important feature of forming in almost all districts.*

Wells.—A well is a hole dug in the ground, to a depth sufficiently great to tap the underground supply of water. This depth will depend on the depth at which the water table is found at different periods of the year. Where soils are homogeneous and composed of fairly porous material, the water level will be found at a uniform distance below the surface, following the contour of

---

* The number of wells in the Presidency is stated to be 567,000: besides this there are over 30,000 *doruvu* wells (Statistical Atlas).

the land with fair regularity. Unfortunately such conditions do not often occur, and when they do, are often in districts where irrigation is not a necessity. In Malabar, for instance, the soft porous nature of the laterite rock makes conditions ideal for well sinking, and valuable as such are for drinking purposes, they are hardly used for irrigation, owing to the exceptionally heavy rainfall which Malabar enjoys. Again in most alluvial soils, water is easily obtained by means of wells, but the soil is frequently found to be unsuitable for such cultivation owing to its close texture, or water is already supplied in sufficient quantities for the cultivation of paddy from the river which as caused the alluvium. There are, for instance in the Tanjore district, unequalled facilities for well sinking, but wells simply are not required. Conditions are however very different in the drier tracts, where the red or black sedimentary soils are underlain by igneous and metamorphic rocks, frequently of hard and close texture. Here the water which passes through the soil or subsoil into the ground, does so along the cracks or fissures which are characteristic of such rocks, especially near their surface. The level of the water table is thus extremely irregular, and the finding of water very haphazard, as the well may or may not cut into a spring. A cursory examination of the wells in such tracts will often show the water standing in adjacent wells at very different levels, the rise or fall of level in one well having no effect on its neighbour, which may draw its supply from a quiet different source. The labour and expense of digging wells, coupled with the uncertainty of the result, it might be thought, would deter farmers from ever investing their money in this way, but such is the value of the water, and so assured is the position of the owner of a good well, that the attempt is frequently made. Naturally enough, people who claim special powers and boast that they can locate the presence of underground water are found, and in places they obtain much credence; not altogether a matter for surprise considering the striking successes which have attended some of these 'water-diviners.' Elsewhere, recourse is had to the reading of omens, as in Coimbatore, where it is said that, if water is poured over a sheep with the appropriate *mantrams*, the place where it first stops to shake itself, marks the site where a successful well may be dug! The matter is of considerable interest, and reference to more scientific methods may be found in the records * of the Bombay Department, who have tested a water finder made by Messrs. Mansfield & Co. The machine is very slow in working and is expensive, costing Rs. 750: it seems successful, though it is not known if it has actually been tested.

Mention may also be made of artesian and sub-artesian wells though few wells of this sort have been utilized for agricultural

* Bulletin No. 38 of 1910. Bombay Department. One is now in the possession of the Madras Agricultural Department.

A-133/1

purposes. Such wells are often very deep, and eventually tap a supply of water which is under sufficient pressure to force it above the level of the ground (artesian) or to within a short distance of the ground (sub-artesian). The boring of such wells has made the greatest progress in Pondicherry,* but recently a number of wells have been sunk in the basin of the Kortaliyar river, north of Madras, and with considerable success (vide Reports of the Pumping and Boring Department, Madras). Artesian wells for drinking and factory purposes have been successfully sunk at Samalkota (Gōdāvari) and Anakāpalle (Vizagapatam).

The cost † of such wells will largely depend on the nature of the rock through which the boring has to be carried.

Tanks.—Notice may next be taken of the surface water intercepted on its way to the sea, which may be diverted to the uses of irrigation, and the first to be considered is the tank. The simplest form of tank is made by throwing a bund across a line of drainage (and therefore roughly along a contour line) so as to intercept the surface drainage which would otherwise pass away into the streams and rivers and so be lost. The construction of these tanks has reached a very high state of development in some parts, and mention may be made of the Cumbum tank, which irrigates an ayacut of 5,000 acres in normal years.

Tank irrigation is in many respects uneconomical and wasteful. Tanks are from their nature shallow, and consequently suffer heavily from evaporation, and though they provide grazing when dry for the cattle of the village in the hot weather, they themselves may occupy up to a quarter of the total area, which is thus lost to crop production. Moreover being still water reservoirs, the silt brought down by the streams is deposited in them, with the twofold result that the lands under them suffer from the absence of silt, while the tank itself tends to fill up and its capacity to become reduced. This in fact is the case with many of the old-established tanks, whose ayacuts have been seriously lessened from this cause.

It cannot be denied, too, that tanks are a frequent source of quarrel and litigation amongst those whose lands are affected by them. When the slope of the land is gentle, a very slight reduction in the height of the water will expose a considerable area of foreshore, with the result that there is a continual struggle between the owners of the land above the tank, who are interested in lowering the escape weir, and the ryots below the tank who are naturally desirous of storing as much water as possible in the tank, and thus aim at increasing or at least maintaining the height of the weir.

---

* Chatterton: Lift Irrigation, second edition, chapter V.

† Excluding the cost of lining pipes, the cost of boring varies from As. 8 a foot in alluvial soil to Rs. 10 or even Rs. 15 in rock. With power appliances, costs should be reduced to Rs. 2 to Rs. 3 a foot.

When such tanks are purely rain fed, that is depended on the run off from the lands draining into them, they serve their purpose, since some form of storage is a necessity. Often however they are supplied by perennial or nearly perennial streams, and in such cases a proper distribution of the water would probably obviate the necessity of a tank at all.

The question of the utilization of tank beds, either by growing trees in them or by permitting their cultivation after they have emptied or in years when the tank fails to fill, is one about which some difference of opinion is held. Anything which causes, or is supposed to cause, an increased deposition of silt is naturally forbidden, while cultivation, which would imply loosening the soil, is also forbidden on the ground that the tank would be made less watertight. It may be questioned whether either of these fears are well grounded, and though it is difficult to lay down general rules, which will hold good in the very widely varying conditions which obtain, the large area included under tank-beds makes the question one of considerable importance. In a case which came under the writer's experience, the prohibition of Cucumber *(Cucurbita moschata)* cultivation in a tank bed had a most disastrous effect; as on clearing was done for the cultivation of the melon crop, the land quickly became covered with a dense crop of weeds, which must have acted much more effectively as a clog on the silt, than the few withered plants which were all that remained of the melon crop after the fruits are harvested. The photographs show how great this change was, and were so striking, that permission for Cucumber cultivation was immediately regranted. (See Figs. 1 and 2.)

It is only necessary to add that such tank beds are extremely fertile owing to their alluvial nature, while shallow wells would, in all probability, strike a supply of water which would last all through the hot weather.

There is also a considerable waste of land along tank bunds and the distributing channels in which the water is taken to the fields, and it is suggested that in view of the increasing difficulties experienced in procuring green manure seeds, such land might be utilized for this purpose. When the plants are perennial, as in the case of some of the *Agathi*, they could be grown on the channel bunds, while the smaller *Sesbanias* and *Tephrosia* would probably establish themselves, with a little assistance, on the larger slopes of the tank bunds. It would perhaps be difficult to prevent abuse, but the waste of space which is such a common feature of tank irrigation seems to call for some cure.

A combination of the well and the tank is seen where wells are sunk in the ayacut or land commanded by a tank, and in such conditions, very intensive cultivation is frequently possible. It is clear that the supply of water in the well is largely affected by the water

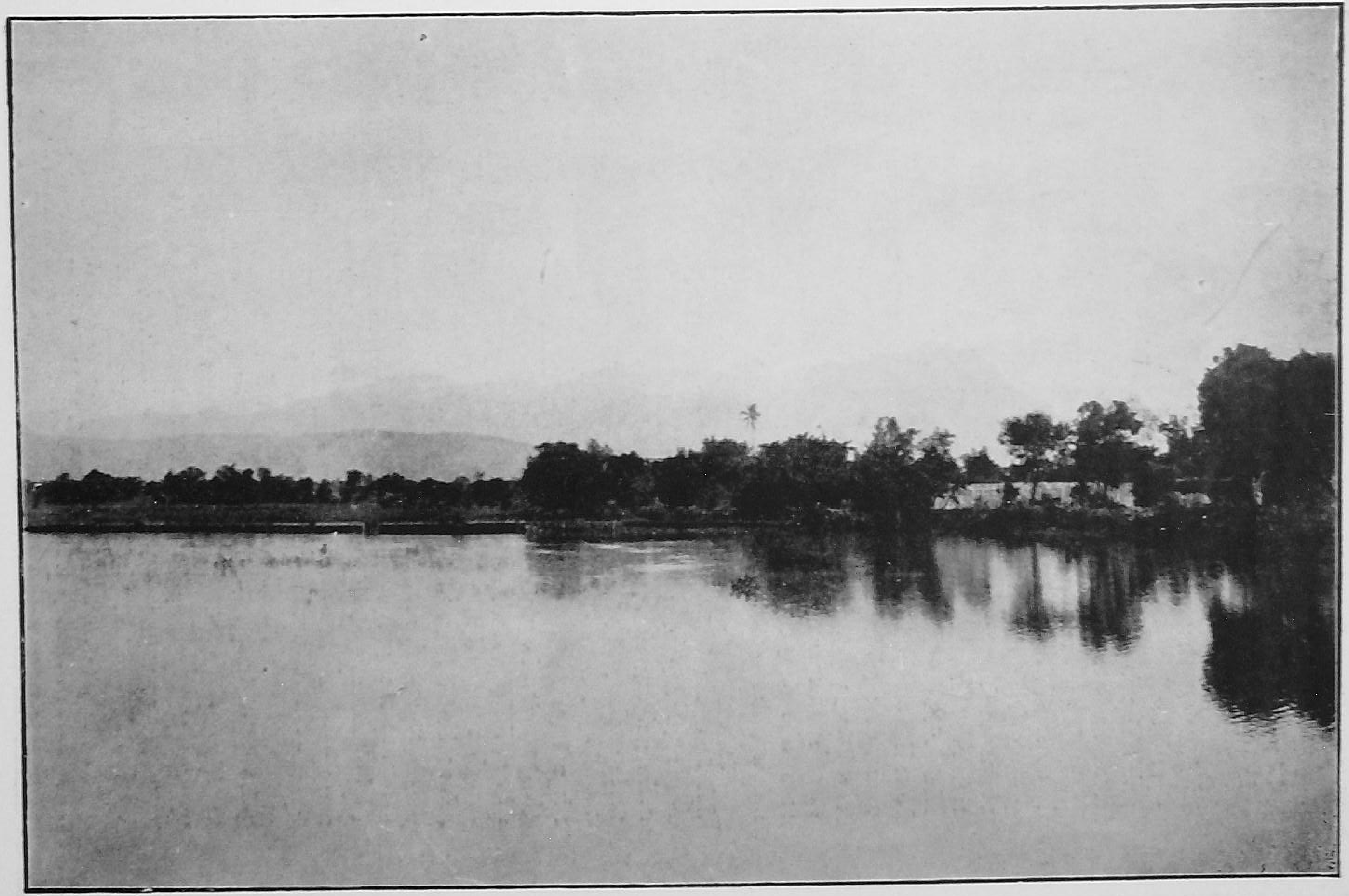


FIG. 1—Tank clear : Cucumber cultivation permitted.

Fig. 2—Growth of weeds due to the stoppage of the hot weather cucumber crop.

in the tank, not only by the direct filling of the well, but by the general rise in the subsoil water due to the surrounding irrigation, but no extra charge is made in such cases, unless as usually happens, tank, i.e., Government water, is used as well as the well* water.

Rivers.—Finally we have the rivers on which to draw for water for irrigation purposes and these form the most important of all. The water from such rivers may be utilized either by gravity or may be lifted by some mechanical means: the former is the most common owing to the large quantity of water which is needed for the cultivation of 'wet' paddy and the extreme popularity of this crop: as an instance of the latter, may be quoted the Divi Island project where water is lifted by powerful pumps to supply some thousands of acres of paddy. The combination of the river and the well, produce what is known as a 'doruvu' well, which is a well sunk half in the river bed and half in its bank. Such wells come under special rules as they are obviously drawing on public supplies of water.†

There are two long established methods of making use of the water in rivers and these are applicable, one when the river is in flood, and one when the river is dry. In order to catch the water at its highest levels, side channels were dug to meet the river, and these were dug at such a level that they would only be filled when the river was running bank full. The water thus diverted was stored in large tanks and utilized for paddy cultivation. The method was crude: and the tanks were often difficult to construct, owing to the very level nature of the alluvial plain which was found on either side of the river: even at their best, only a very small proportion of the river water could ever be put on to the land. Such canals were for instance, in existence before the construction of the Kistna anicut at Bezwada, diverting the water from that river. A variation on this method is still practised in the south, to utilize the waters of the Cauvery, the Coleroon and the Amarāvati. This is to construct temporary dams, known as *korambus*, which are built out from the head of each channel when the supply in the river begins to run low. They are made of sand, earth, branches, grass, bamboos and even logs, and are of course swept away by each fresh, being reconstructed again when the need arises. This is an improvement on the flood channel and a larger proportion of the river water is impounded by these *korambus*.

Another method of extracting the water from rivers—in this case from their sandy beds during the period when they are dry—and one which has evidently been practised for many years, is by spring

* The rules governing such cases will be found in Board's Standing Order 6, paragraph 5.

† Board's Standing Order 1, section 7.

channels.* These are long channels which are excavated in the beds of the larger rivers like the Hagari, the Tungabhadra and the Pennar. They often extend for several miles, and starting at their head, below the water level in the river bed, are taken down stream at a flatter gradient than that of the river bed, and the country round, with the result that they are soon high enough to be taken through the bank and gradually above the level of the land where they can be used for irrigation. The supply is divided into a definite number of shares, and the users of the water are bound to provide one cooly for each share, whenever the water officer summons them, for in the digging and the clearing of the channel much labour is required, particularly in the portion in the river bed, which is swept away whenever the river flows. The distribution is ingenious, a flat log of wood is fixed horizontally in the channel so that all the water flows over it uniformly. Vertical divisions can be inserted wherever necessary, to divide the total flow into any number of proportionate parts, according to the number of shares irrigated from each channel. (See Fig. 3.)

The upkeep of these division weirs is in the charge of the water official who gets one or more shares free for his labour: careful inspection is necessary, for unscrupulous owners will often surreptitiously make a hole behind the bar, and thus obtain far more than their fair share to the detriment of their neighbours.

These methods have the merit of antiquity, but are uncertain, and in the case of the spring channel extremely laborious. A much more effective method of utilizing river water is by the construction of a permanent dam or anicut across a river, so that the level of the water is raised to a height sufficient to command land in the vicinity. This system has also the merit of antiquity and in the case of the smaller rivers there is no doubt that anicuts have been in existence for many years,† but it is within the last century that the extension of this system of irrigation has been most marked. The magnificent anicuts across the Kistna and the Gōdāvari rivers, which this country owes to the genius of Sir Arthur Cotton, were built between the years 1848 and 1855 and have not only themselves proved financially successful, but directly and indirectly have brought wealth and prosperity to a very large section of the country. The magnitude of these works may be judged from the fact that the Kistna dam alone cost seven lakhs while 137 lakhs was spent on the whole Gōdāvari system, sums which would be largely increased were the work to be done today. Very elaborate precautions have to be taken to prevent damage to the anicuts themselves, while the scouring sluices which are

* See Lift Irrigation. A. Chatterton, Chapter XI, page 177 (second edition).

† It is supposed that the Grand Anicut between the Cauvery and the Coleroon was first built under the Chola kings.

FIG. 3--Method of dividing water-supply (Chenganur, Bellary district).

intended to prevent the accumulation of silt, and the canal sluices which regulate the amount of water let into the canals need very careful attention.

Accurate distribution is insured by a telephonic system which places the head officer in touch with the whole system, so that he can direct the water where it is most needed, or quickly deal with excess, with the least possible delay, and by a very elaborate system of sluices dealing with smaller and smaller distributaries, the water is gradually distributed to the whole area.

These systems are favoured by the natural slope of such alluvial tracts, which slope generally away from the river, owing to the thicker deposits of silt which occurred near the river whenever it topped its banks, while such alluvial soils are ideal for the cultivation of paddy, the only crop possible in such conditions.

Another very striking project which has been successfully engineered, is the Periyār Scheme, called after a river in the hills of Travancore, which formerly ran westwards to the sea. This was dammed up, and by means of a tunnel cut through the hill, its waters were diverted eastward to the thirsty plains of Madura, where they now irrigate 150,000 acres of paddy. This system varies from the others we have considered, firstly that there is no silt in the water, which runs practically clear from the high hills, and secondly that the soil commanded by the water is not alluvial in nature, and is not therefore particularly rich. Owing to these two contributing causes, the problem of maintaining the fertility of the land has attained a special prominence in this tract, and it is perhaps this scarcity of manure which has made the Madura ryot so quick to realize the value of nightsoil for his paddy. Alkalinity is also a danger which is on the increase, owing to the general rise of the subsoil water.

The problem of making fuller use of the water which, as is proved by the existence of spring channels, must be stored in the sandy beds of large rivers, is one which offers considerable difficulty, and one which has not yet been tackled, except on a small scale. The reason is that the water cannot be drawn from one place, inasmuch as the sand becomes sucked dry, while the friction of the passage of the water through it offers considerable resistance. A solution of the difficulty which has been suggested by Mr. Chatterton, is the erection of a central electric power-house, from which power may be distributed to numerous small installations, which will be of the nature of doruvu wells, and will not interfere with each other.

3. The problem of lifting water.—The importance of some means of lifting water, so that it may be applied at or near the surface of the ground, may be concluded from previous sections, where it was shown that though for a certain class of irrigation, namely the cultivation of wet paddy, the water was usually

made to flow on to the land by gravity, yet there was a very considerable amount of garden cultivation carried out with the help of lifted water.

Looked at in its simplest form, the lifting of water is a purely mechanical task, which can be expressed in definite terms: the raising of a certain weight a certain height at the cheapest rate. The problem is however complicated by several other factors. It is clear that the water must be lifted in some receptacle, which may be either some kind of a vessel or bucket, or else a pipe up which the water is pushed or pulled. In the former case we have to consider the methods to be adopted in emptying the bucket. The depth of the water to be lifted will probably vary with the season, and thus the lifting arrangement must be able to accommodate itself to work at different depths. The apparatus must to the highest degree be safe and reliable, and in this way differs to some extent from other apparatus, such as an oil crusher or a chaff cutter where a breakdown means only loss of time: the stoppage of an irrigation plant may imply the death of the crop which was being watered by it and may thus mean a very serious loss.

It may be said at once that these various difficulties can be and have been easily overcome by engineering science, provided the amount to be lifted is sufficiently large. Unfortunately such is not usually the case, and though considerable progress has been made in designing and constructing pumps or other apparatus suitable for small quantities, it is the case even now, that the instances in which small power plants can be profitably installed are comparatively few and far between. It becomes of great importance then to study the various lifts which the farmer has at his control, and these may be classed into two—those in which *bullock* power is made use of, and those in which *human* labour is alone utilized.

Although in certain districts, manual lifts are used, the bullock mhote in one or other of its forms, is the commonest means adopted at present for lifting water for irrigation purposes from wells. The mhote, or leather (sometimes iron) bucket is common to all three forms, the difference appearing only in the method in which the power of the animals is utilized.

In the first and most common type, which we may call the *single* type, the animals exert their force, by moving down a comparatively flat incline, usually at a slope of about 1 in 5, lifting behind them the bucket (kavalvi) which is discharged by means of an ingenious 'tail' which will be described later. After discharge, the bullocks back up the slope until they reach the top by which time the bucket will have again reached the surface of the water, when the process is repeated. (See Fig. 4.)

In the second or *double* mhote, the slope is made much steeper, 1 in 3½ to 1 in 2, and the animals are unyoked at the bottom of the ramp and return walking up a path at the side. Meanwhile the

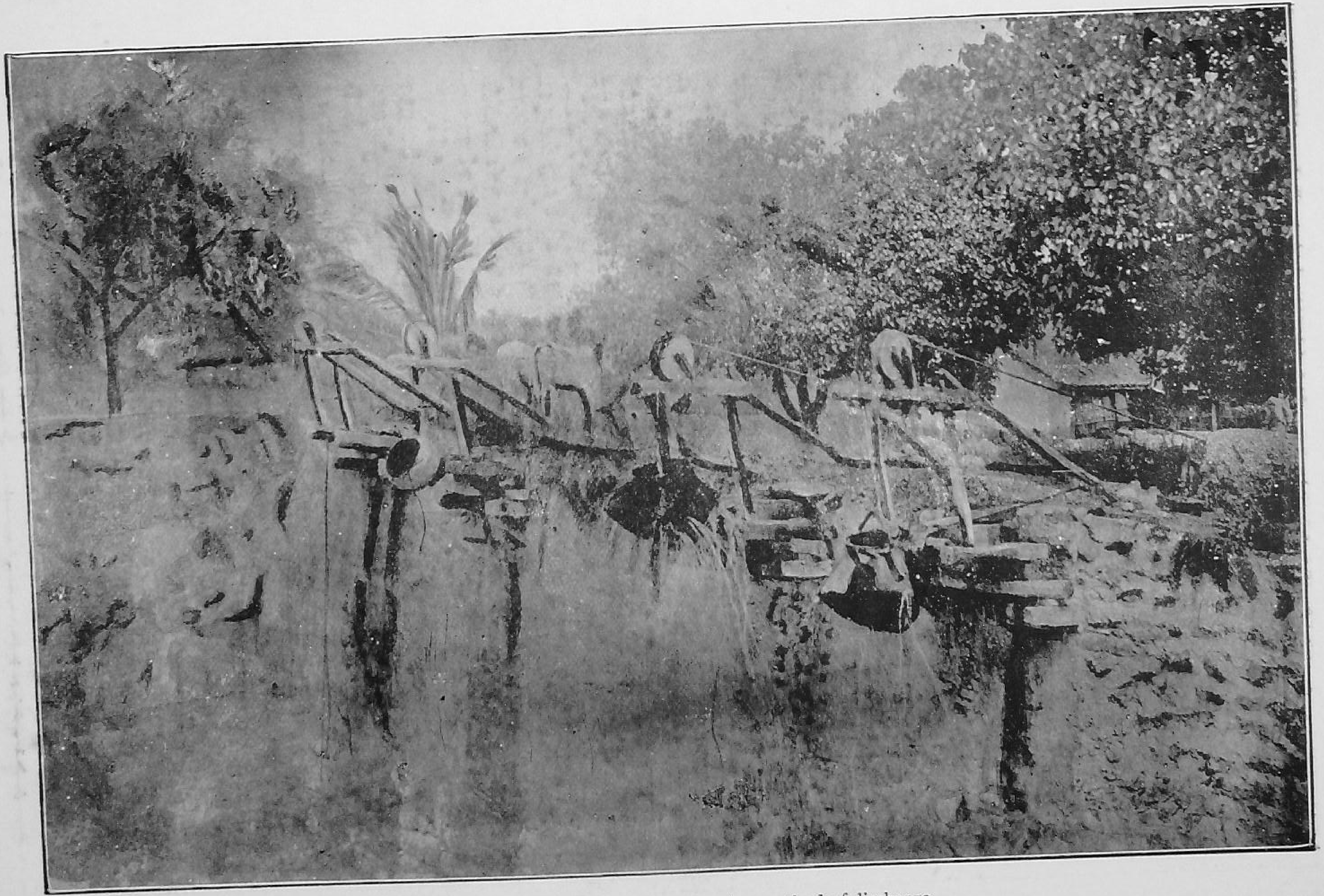


FIG. 4--A four mhote well : showing method of discharge.

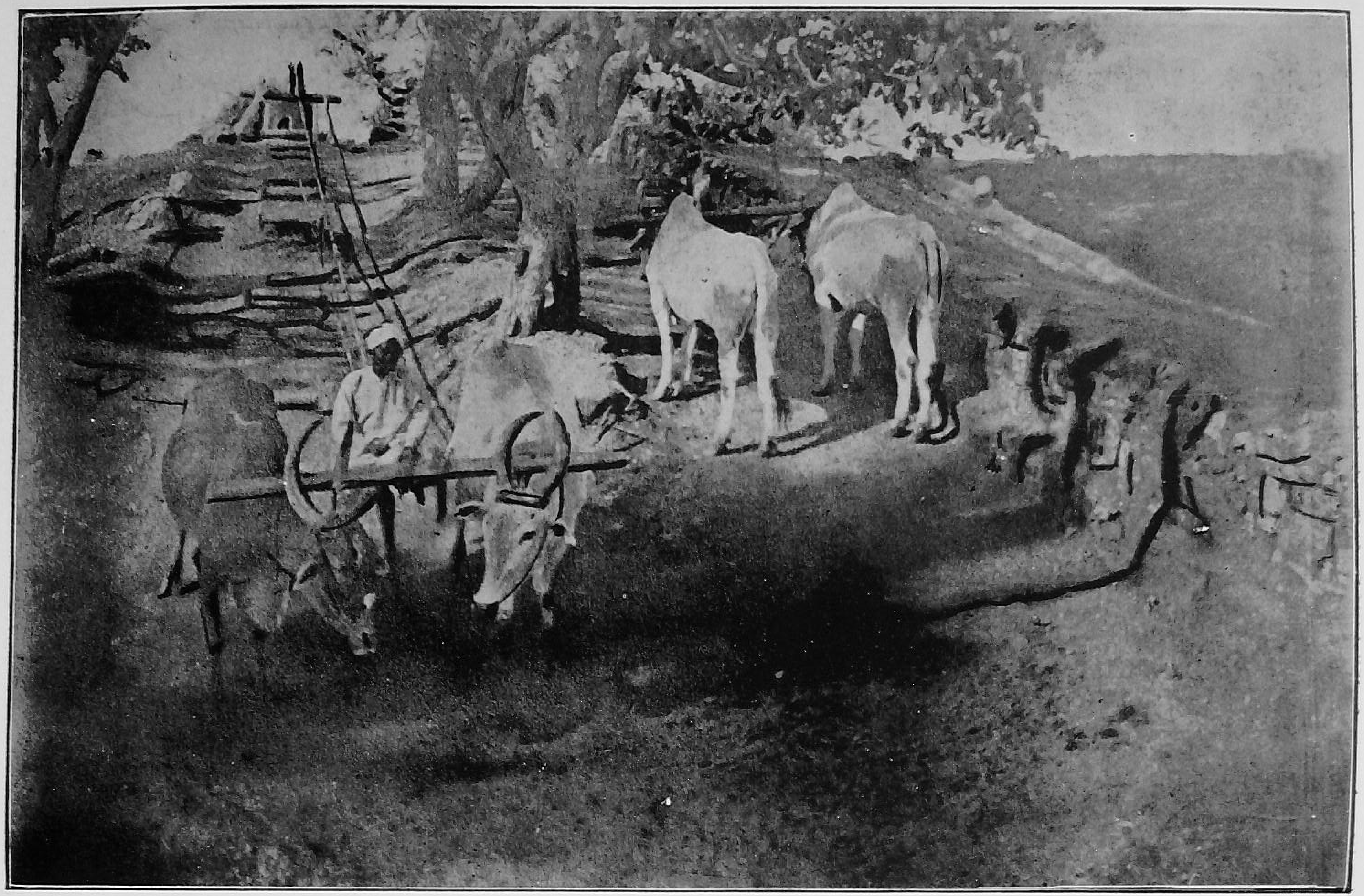


FIG. 5—"Bellary" or double mhote.

bucket descends into the well by its own weight, pulling up the driver who accompanies the returning rope to the top, where he fastens it by a simple loop and peg, to a second pair which is waiting there. Usually only two pairs are worked together, but three pairs are sometimes seen in use at a deep well, while it would be possible of course to use only one pair. It is convenient however to refer to this as the 'double mhote.' It is commonly seen in Bellary, but is found elsewhere. (See Fig. 5.)

The third system is the *circular* mhote, and in this case the bullocks walk in a circle on level ground, winding up the rope to which the bucket is attached on a circular cylinder. The bullocks reverse while the bucket is discharging. There are frequently two buckets fitted, one of which is ascending while the empty one is descending so that the process is made continuous. Specimens of this mhote may be seen in South Arcot, but are not very largely utilized even there, while in other districts they are generally unknown.

In comparing these forms of lifts,* it must be borne in mind that the value of a water lift worked by bullock power depends partly on its mechanical or constructional efficiency, and partly on the efficiency or the method adopted to utilize the power of the animals working it. The strength of an animal may be directed to the performance of 'internal' and 'external' work: 'internal' work being merely the transference of the animal's own body from one place to another, and 'external' work the moving of anything outside its body. A bullock walking along a level road performs only 'internal' work; if in addition he pulls a cart, he performs 'external' work as well.

If a bullock is made to raise its own body against the force of gravity it performs internal work only, but if in descending, it is made to raise an equivalent weight, it will perform usual work, and in the most efficient possible way, because all its energy is utilized only in moving its own body. On a horizontal road and walking at a natural gait, a bullock weighing 800 lb. can exert a pull of one-seventh of its own weight, i.e., about 1 cwt. (112 lb.), and this is mechanically equivalent to walking up a slope of 1 in 7, for 7 to 8 hours a day. The latter work is obviously less tiring for the animal, in fact it could walk up a much steeper slope with comparative ease. Chatterton (*loc. cit.*) calculates that an animal can do twice as much work with the same ultimate expenditure of energy, when engaged in raising its own body against the action of gravity, than in any other way it is feasible to employ it.

With the much greater slope of the double mhote, rendered possible by the fact that the cattle have not to be backed up the

---

* Much of the next few sections is taken from Bulletin 35 of the Department of Agriculture by A. Chatterton.

ramp, the weight of the animals is much more effectively utilized, and a bigger bucket* can therefore be lifted for the same size of cattle. This lift has also an advantage in that it avoids the process of backing up the ramp, which is hard on the animals, and wears them out considerably. For these reasons the double mhote is certainly superior for deep lifts, and for big cattle. In the case of shallow wells, where the cycle of work done with each lift is small, the time necessarily taken in disconnecting the cattle and attaching the other pair, bears a much greater proportion to the total.†

The case of the circular lift is different, as in this, the *weight* of the animals is not utilized at all, but only their *strength*; the animals have to exert their power by pulling at a dead weight along a level surface. The lift consequently possesses a low efficiency, and for this reason need not be considered further.

These systems, and of these the first two are by far the most important, are those commonly employed for the removal of water from wells by bullock power. The importance of the problem has tempted many inventors to produce improved lifts for which increased efficiency is claimed. It may be said at once that these have not in a single case become very popular, nor have any of them, when under trial, shown any marked advantage, over the ordinary single or double mhote. This is largely because, being more complicated, they have implied careful construction, if the *mechanical* efficiency was not to suffer. Any large moving parts

---

* The buckets used commonly at Coimbatore are 45 gallons and 60 gallons for the single and double mhotes.

† A little calculation will make this clear: the adoption of a steeper slope will mean a saving in the time which the animals take to move down the slope, which may be put at 1 second for every five yards run: the fact that they walk up instead of backing up, means that they save time on the return journey, and at a greater rate, say 1 second for every two yards run, while they lose 2 seconds in the process of disconnecting and connecting the animals. In the case of a well of thirty feet (ten yards) depth, from which forty buckets an hour are lifted, the sum is—

Gain	Run down	40 × 2	= 80	seconds.
	Return up	40 × 5	= 200	,,
			= 280	,,
Loss		40 × 4	= 160	,,
	Gain per hour		= 120	,,

If the well is nine feet in depth, ninety buckets for an hour may be lifted and the sum is—

Gain	Run down	90 × $\frac{3}{5}$	= 54	seconds.
	Return up	90 × $\frac{3}{2}$	= 135	,,
			= 189	,,
Loss		90 × 4	= 360	,,
	Loss per hour		= 171	,,

These figures are purely imaginary, and are not based upon experiment.

must move on accurately shaped surfaces, or else the losses due to friction will counterbalance any other advantages they possess. This sends up the cost to a point which makes such lifts unpopular, and the mhote holds its position as much for its cheapness as from its efficiency and ease of repair; the importance of this last has already been emphasized. The attention of inventors has been directed to various parts of the apparatus. The late Rao Bahadur C. K. Subba Rao who devoted much time and money to this question, produced a mhote in which the power of the animal was utilized by means of an oscillating platform, from end to end of which the bullock was walked. This 'seesaw lift' is,

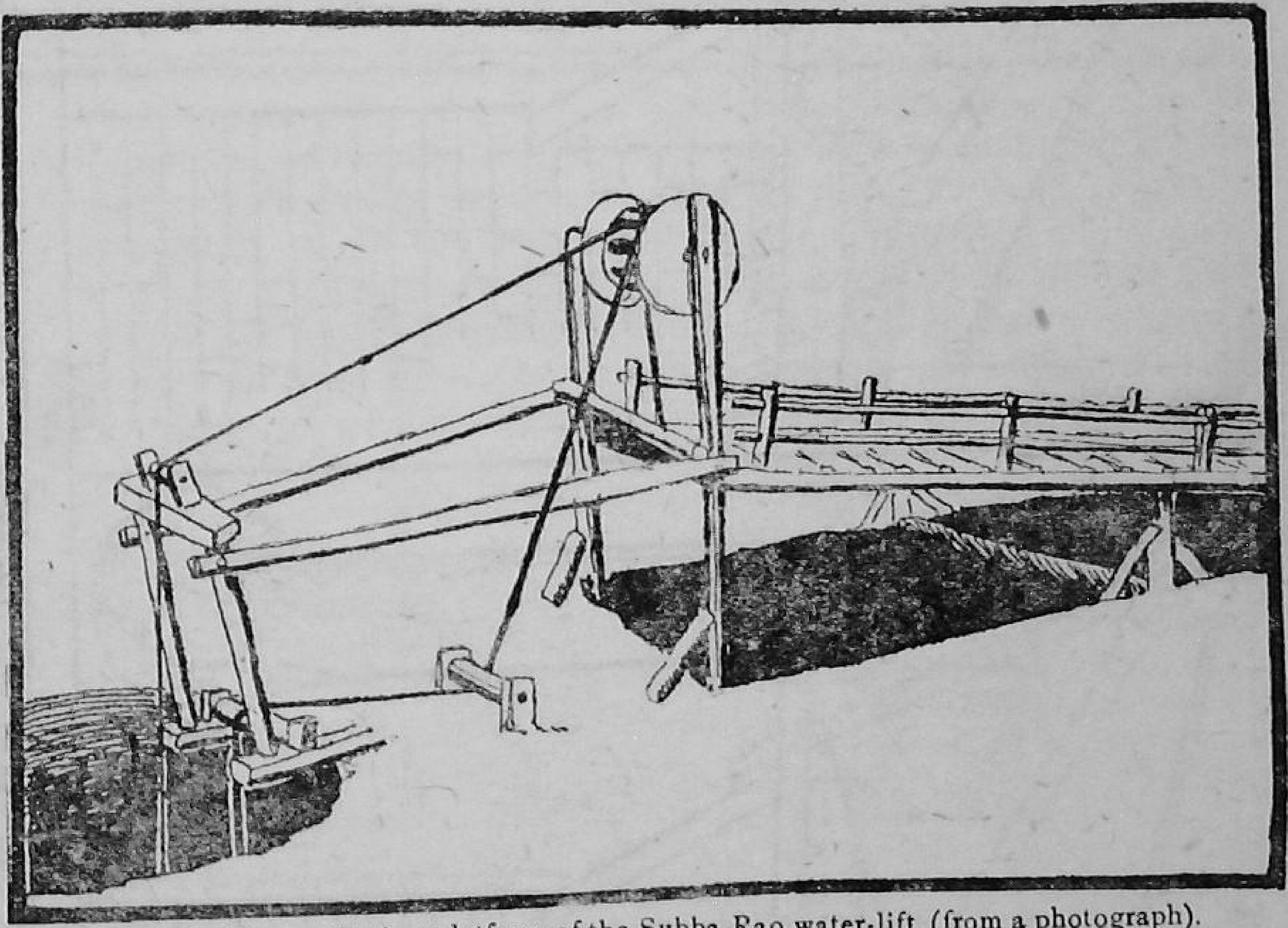
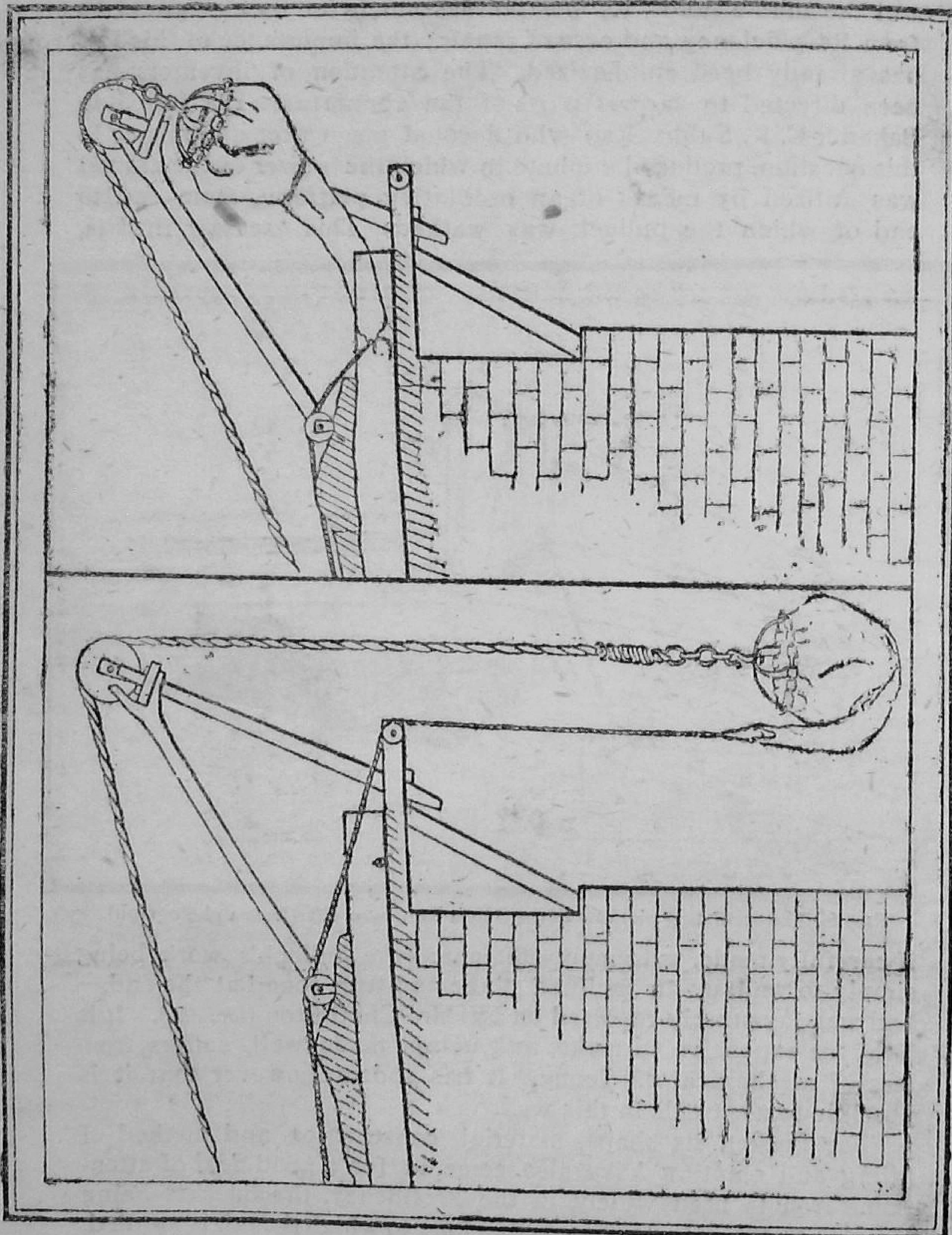


FIG. 6—The oscillating platform of the Subba Rao water-lift (from a photograph).

if carefully made, extremely efficient:—the bullock's work being simply to walk up an inclined plane and turn round at the end,—and was favourably reported on by Mr. Chatterton (*loc. cit.*). It is however expensive to make, and unless made well, suffers from loss of mechanical efficiency. It has shown however that it is possible to use cattle in this way.

The bucket, its shape, material, construction and method of filling and empting have also come in for a good deal of attention. Iron is used widely in the Presidency, the buckets being circular or cubical in shape, with a hole to which the tail is applied, on the under side, in the centre or slightly to one side. The advantage of the iron bucket lies undoubtedly in its rigidity, which makes it much easier and quicker to fill. It is a fact that

where they are used, the mhotes are worked by boys, who would not be strong enough to fill collapsible leather buckets. This advantage is also more marked in the case of low lifts.



The method of emptying the bucket is extremely simple, and it would seem difficult to improve upon it. The tail is about four feet long, so that when doubled up the end comes above the level of

the water in the bucket. It is kept in this doubled up position by the tail rope, a light rope (three tail ropes usually make one mhote rope) which is fastened at one end to the end of the tail, and at the other to the mhote rope near the yoke, running over a separate pulley just above the opening of the water trough. The length of the tail rope is so adjusted that when the kavalai has reached the top, the tail rope pulls the tail towards the trough and thus effects the discharge of the bucket.

This discharge has the great merit of being gradual and at the same time rapid, while it requires no extra force on the part of the bullocks. The tail rope is also useful in tilting the bucket when in the well and helping to fill it quickly.

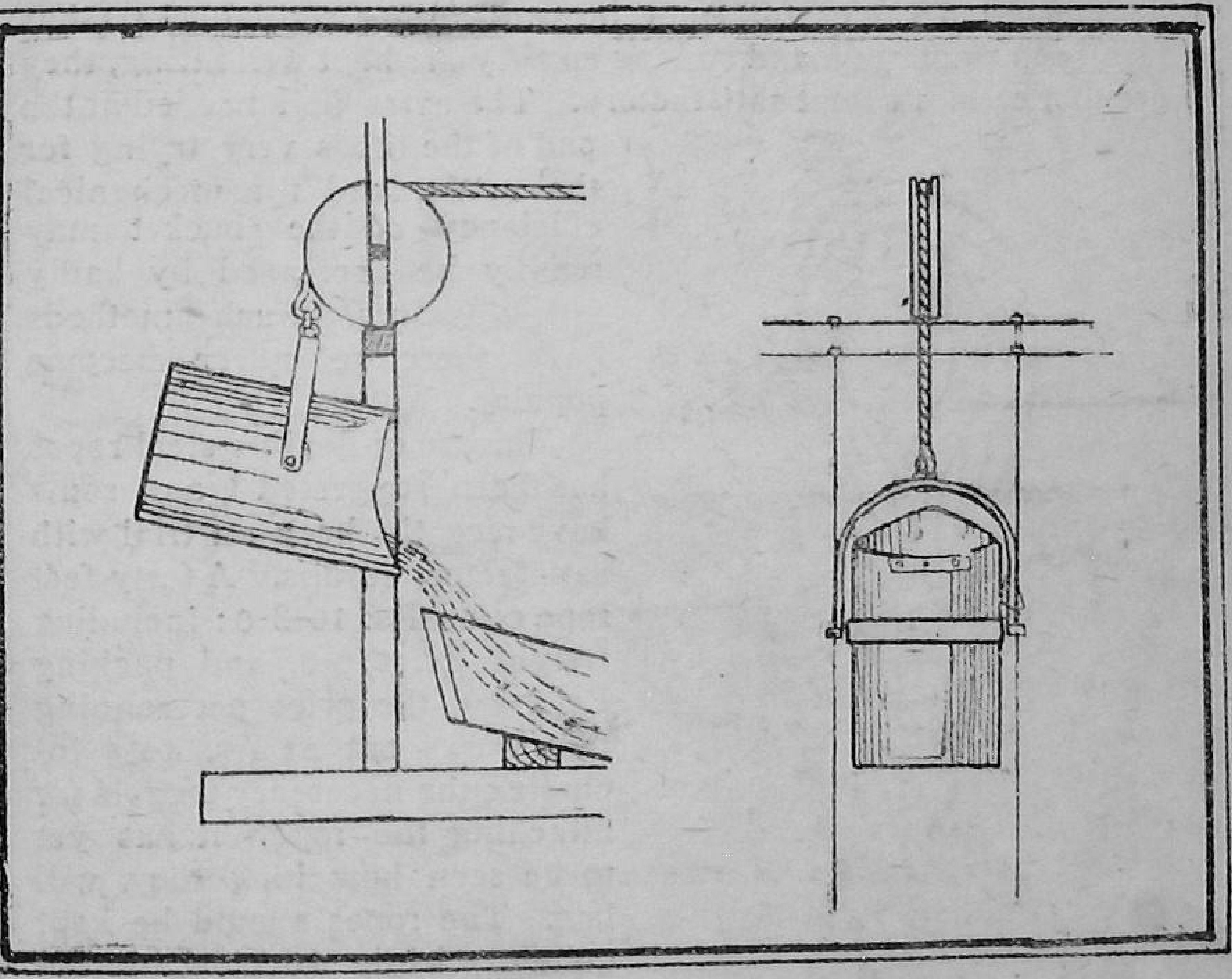


FIG. 8—Tilting bucket as suggested in Stoney's lift.

Other methods have been suggested; tilting buckets were employed in Stoney's waterlift and are described thus: "The "buckets were suspended in a stirrup by two adjustable pivots, "attached to the bucket very slightly above the centre of gravity "of the bucket when full of water. The mouth of the bucket is "inclined, and the lower ends of the stirrup are turned outwards "and formed into rings sliding on steel wires which are suspended "in the well from screwed eyebolts attached to the framing above. "The wires are fastened by some convenient means to the bottom "of the well, and act as guides to the bucket ascending and descend- "ing and prevent it from either turning round or swaying to and

"fro, and thus striking the sides of the well or the second bucket. "On the bucket being lowered into the water it turns horizontal and "as it sinks fills with water. On being drawn up it assumes a "vertical position and rises steadily till the discharging level is "reached, when the upper side of the inclined mouth comes into "contact with an iron bar fixed across the framing of the lift, and "the stirrup continuing its upward motion causes the bucket to "revolve about the point of contact of the bucket with the iron rod, "and thus discharges its content into the delivery trough." These have been seen by the writer in use in Palakod, a village in the Dharmapuri taluk of the Salem district: their existence elsewhere is unknown.

The use of valves for emptying and filling rigid buckets has also been suggested, and so long as they are kept well fitting, they are to a certain extent satisfactory. The extra pull needed at the end of the lift is very trying for the cattle, and the mechanical efficiency of the bucket may readily be decreased by badly fitting valves. Such methods have therefore never become popular.

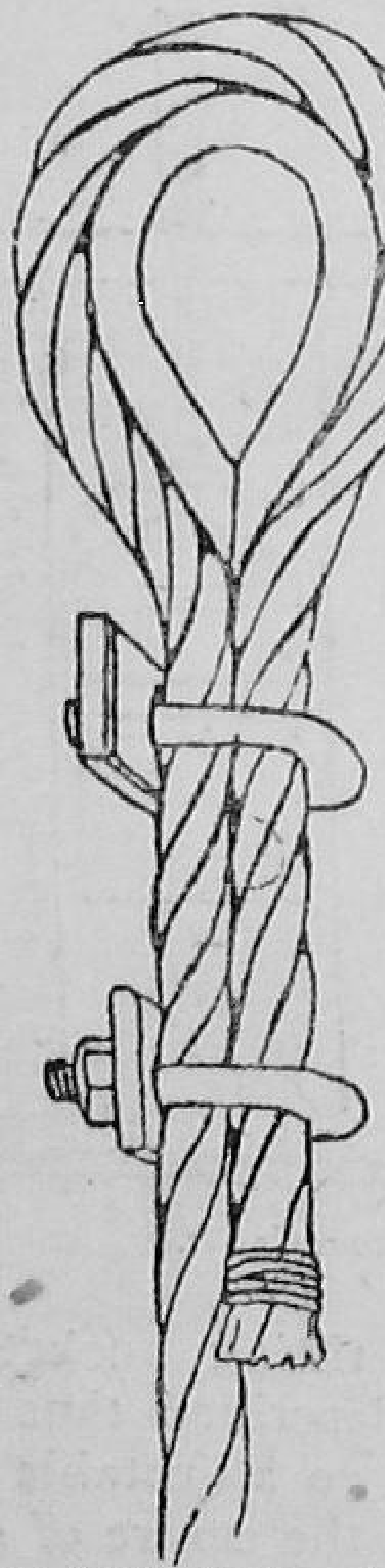


FIG. 9—Method of making loop in steel rope.

The use of flexible steel ropes has been suggested * and some have recently been on trial with satisfactory results. A forty feet rope costs Rs. 10-8-0; including freight Rs. 2-9-0, and packing Rs. 1-4-0, the price per running foot works out at As. 4-7 † including the necessary toggels for attaching the rope. It has yet to be seen how long they will last. The ropes should be kept quite dry while working, by providing the bucket with a chain long enough to keep the main rope out of the water.

The methods by which manual power is made use of for the purpose of lifting water are very numerous and utilize in varying proportions the weight, the strength and the skill of the individual working them.

* Bombay Department: Annual Report of Experimental Work, Dhulia Agricultural Station, 1911-10. Madras Departmental Calendar, 1916—17.

† These are pre-war prices.

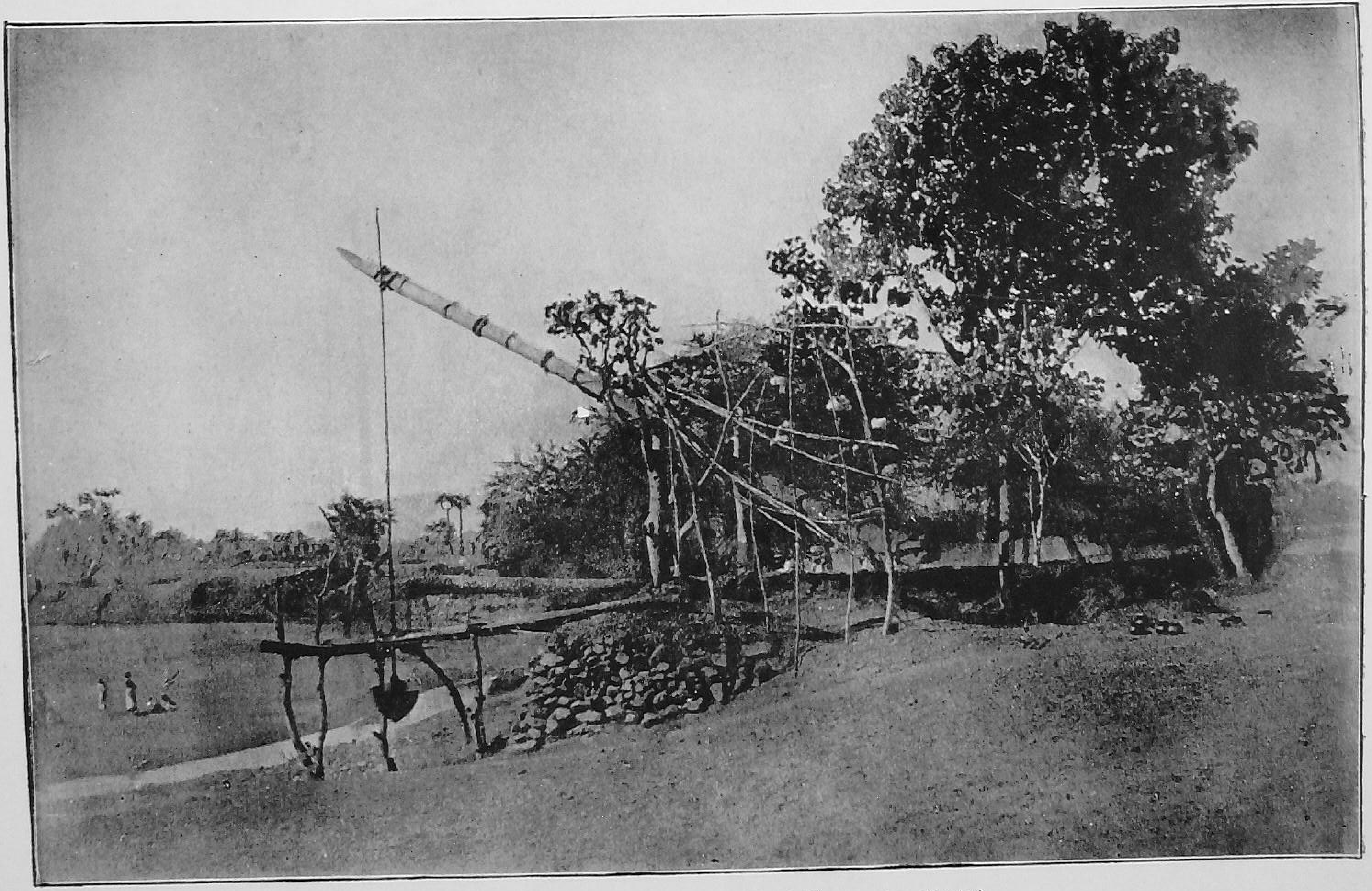


FIG. 10—Picottah worked by four men (Tuni, Vizagapatam district).

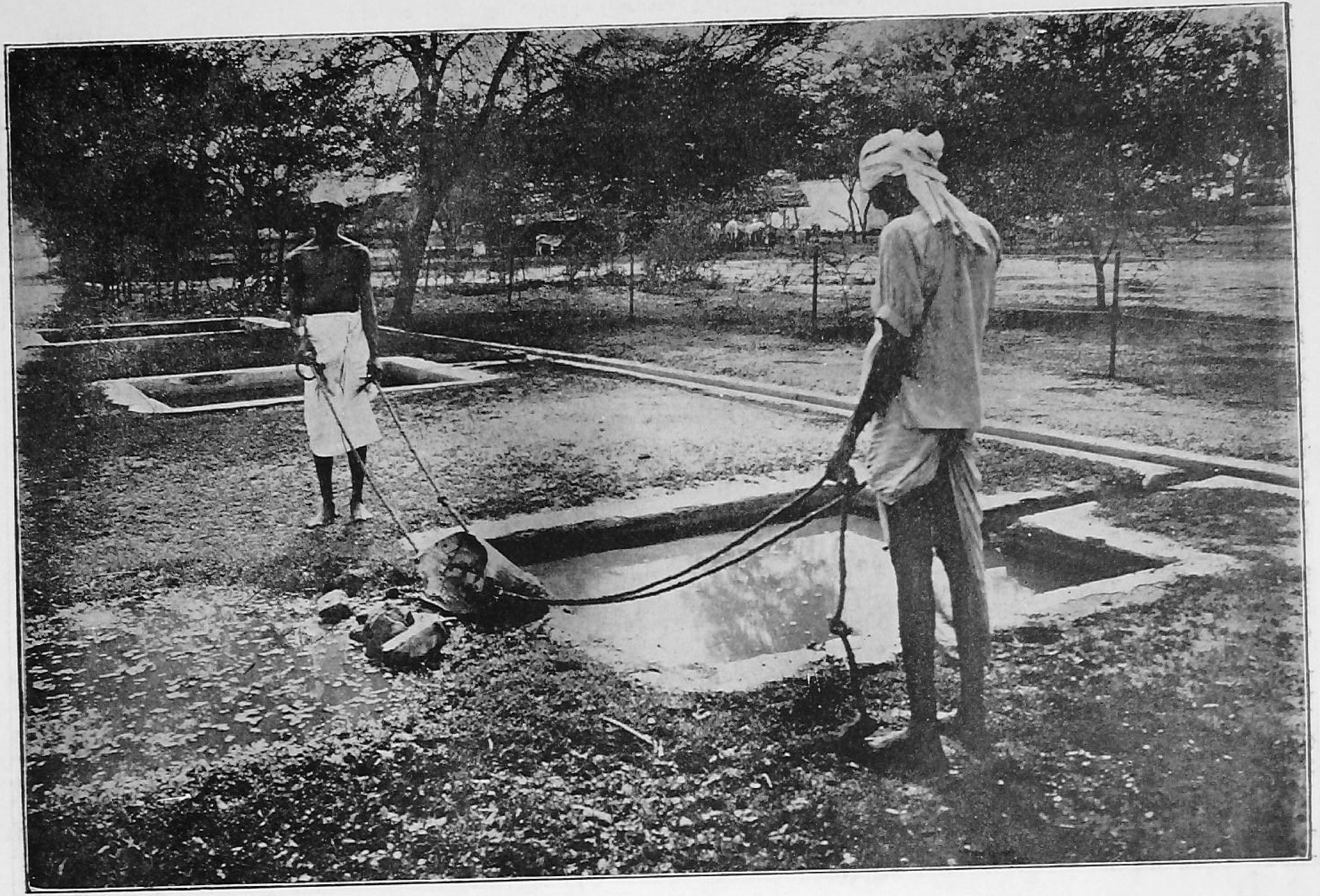


FIG. 11—Swing basket.

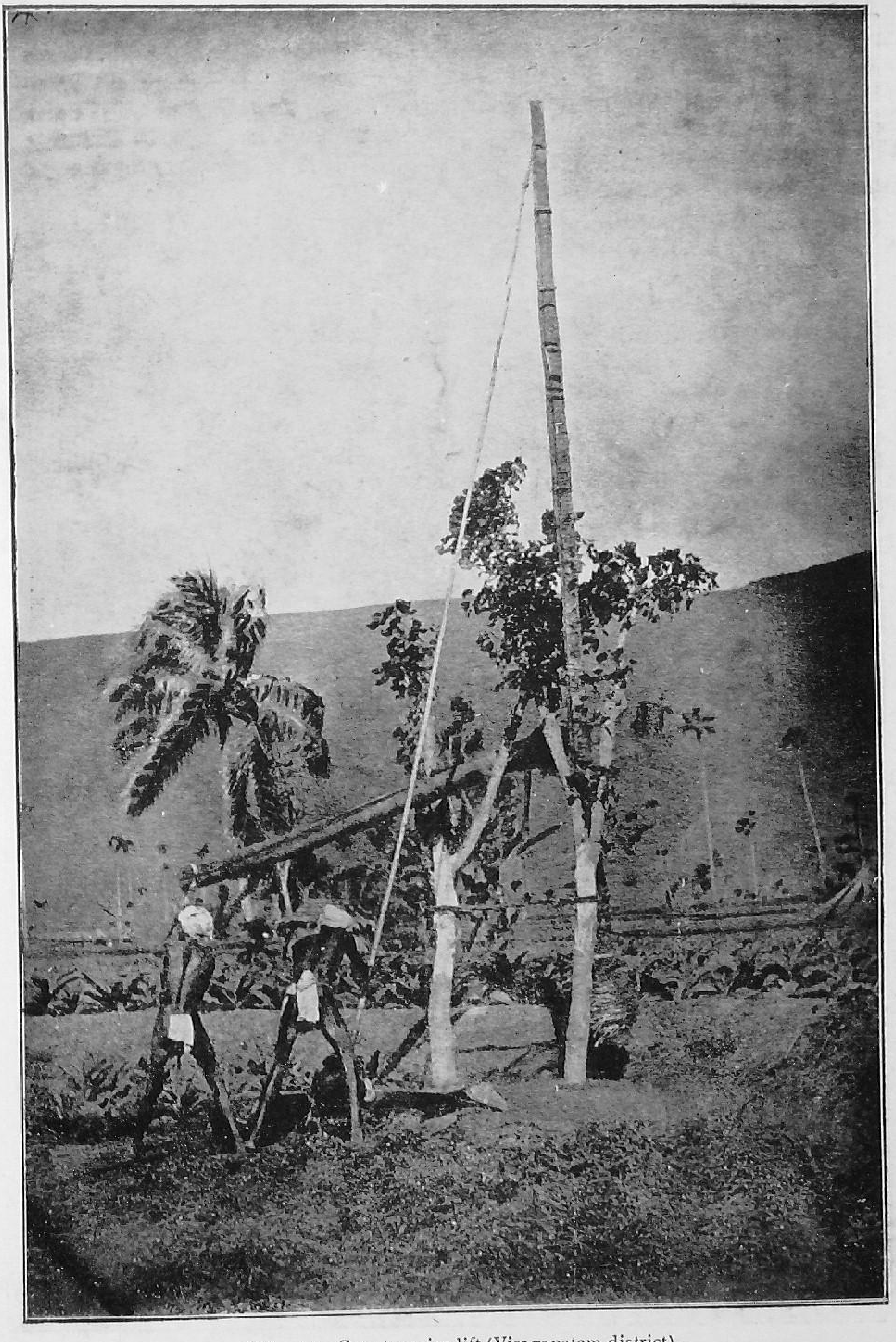


FIG. 12—Counterpoise lift (Vizagapatam district).

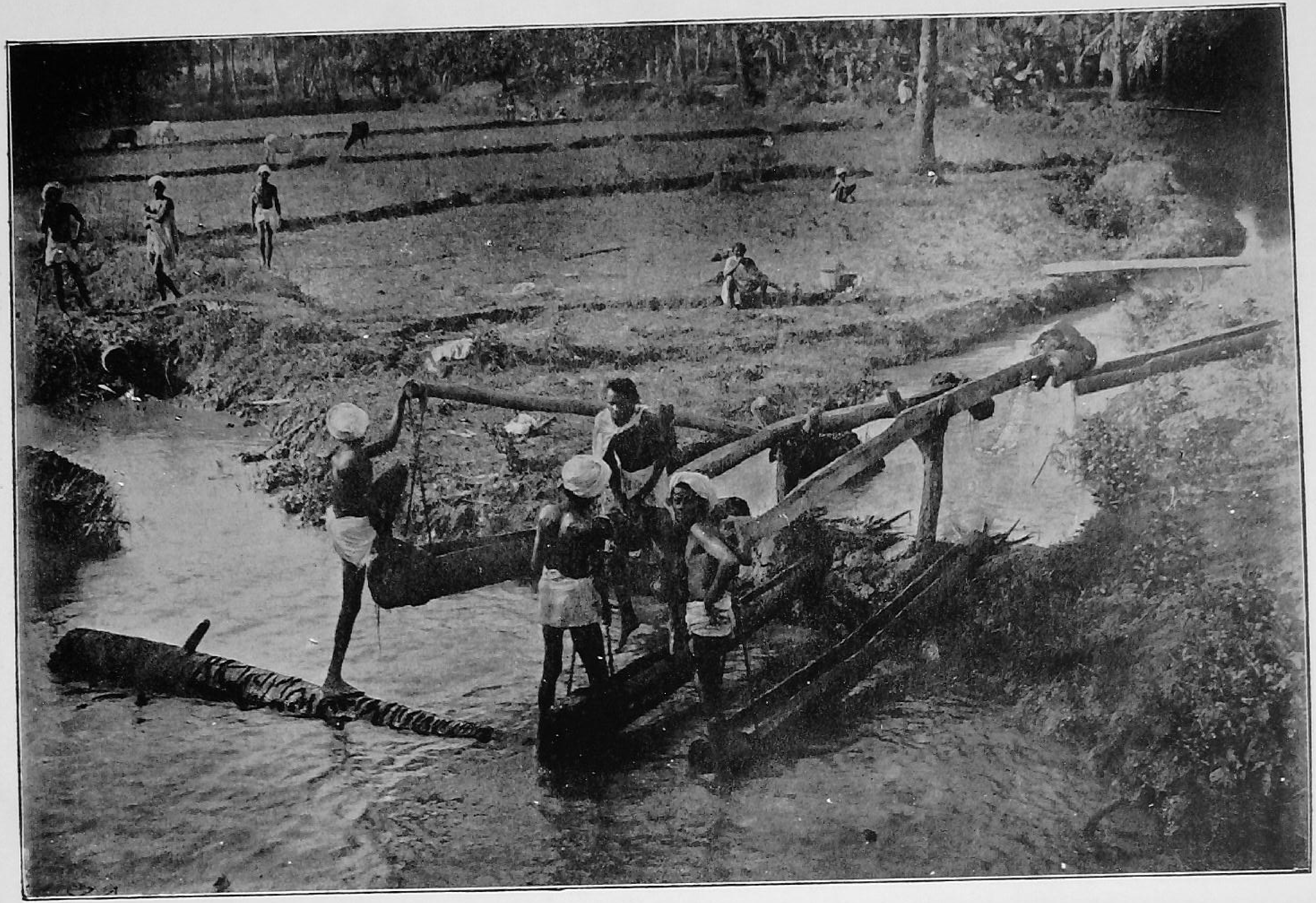


FIG. 13 - Karim (Gōdāvari district).

The commonest is probably the *picottah.* The picture shows that the motive power is derived from the weight of the coolies on the oscillating beam: their work being to be continually climbing uphill and swinging the lever up and down. Here we evidently have the principle of the oscillating platform referred to above, only, as we are dealing with human beings and not animals, we can use a single beam instead of a platform, at greater efficiency and less cost. The picottah is an extremely *efficient* lift, as may be seen by referring to Mr. Chatterton's experiments *: in which the *coefficient of utility*, i.e., the useful work done in foot pounds per hour, divided by the weight of the man or animal working the lift, came out very much higher with the picottah than in any form of bullock lift. The only criticism that can be made of the picottah is its danger. After long spells of work, and especially at night, when advantage is taken of the moon to push on with irrigation, the men become tired and a false step may easily result in a broken leg. By linking up the overhead lever, which must have a motion equal to the depth of the well, with a shorter lever, oscillating about a centre at the level of the ground, it should be possible to arrange a safer form of this machine. The number of coolies on the beam varies from one to three: each taking it in turn to manipulate the bucket. The chant of this individual who counts each bucket as he discharges it, and sends the water on its way with a brief prayer, is heard all day in certain seasons in South Arcot, where the picottah is a very familiar object. (See Fig. 10.)

The *swing basket* needs two men, one standing on either side holding the ropes. (See Fig. 11.) It is suitable only for low lifts up to a few feet, and it is noticeable that the bulk of the work is done not by the arms, but by the stronger muscles of the back, in fact, the man throws his *weight* against the ropes in somewhat the same way as a rower throws his weight against his oar. Two baskets are frequently worked at the same place by two pairs of one man lifts.

The *counterpoise lift* in some form or other is very common. The oscillating lever appears again, in this case weighted at the shorter end, so that when the bucket is full the weight on either side is approximately equal. This means that the bulk of the work is done not in *lifting* the full bucket, but in *pulling down* the empty one, that is, in raising the weighted end. In other words, the man utilizes his weight as much as possible, by working with gravity and not against it. (See Fig. 12.)

This arrangement is suitable for lifts of some depth. For smaller lifts, where the cycle of operations is shorter, it is essential to have something which is very easily filled and emptied, and for this the *karim* or *trough lift* is suitable. The method of working will be seen from the picture below. (See Fig. 13.)

---

* Chatterton *loc cit.*

The trough is made of a hollowed-out palmyra, or of wooden planks, but recently iron troughs have been introduced which have the benefit of being lighter: this means less friction on all bearings, and consequently greater efficiency. A variant of this is the swinging shovel used in Malabar, where the water is literally shovelled uphill, the weight of the shovel being taken by a rope fastened to a tripod.

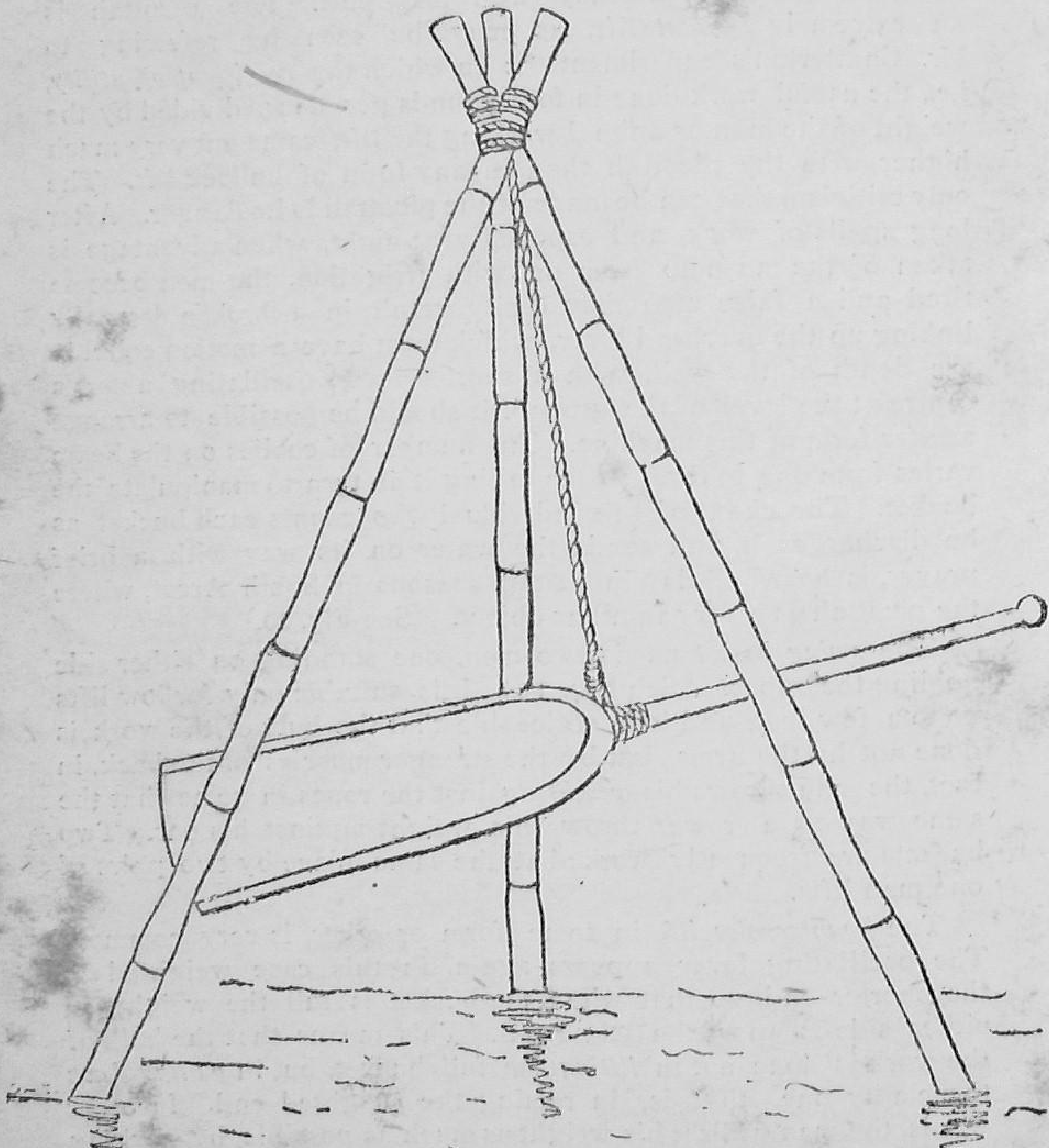


Fig. 14—Malabar water shovel.

Of more complicated apparatus, may be noted these which include a wheel in their composition such as the endless chain arrangement or more simply an ascending and descending bucket shown in the picture. (See Fig. 15.)

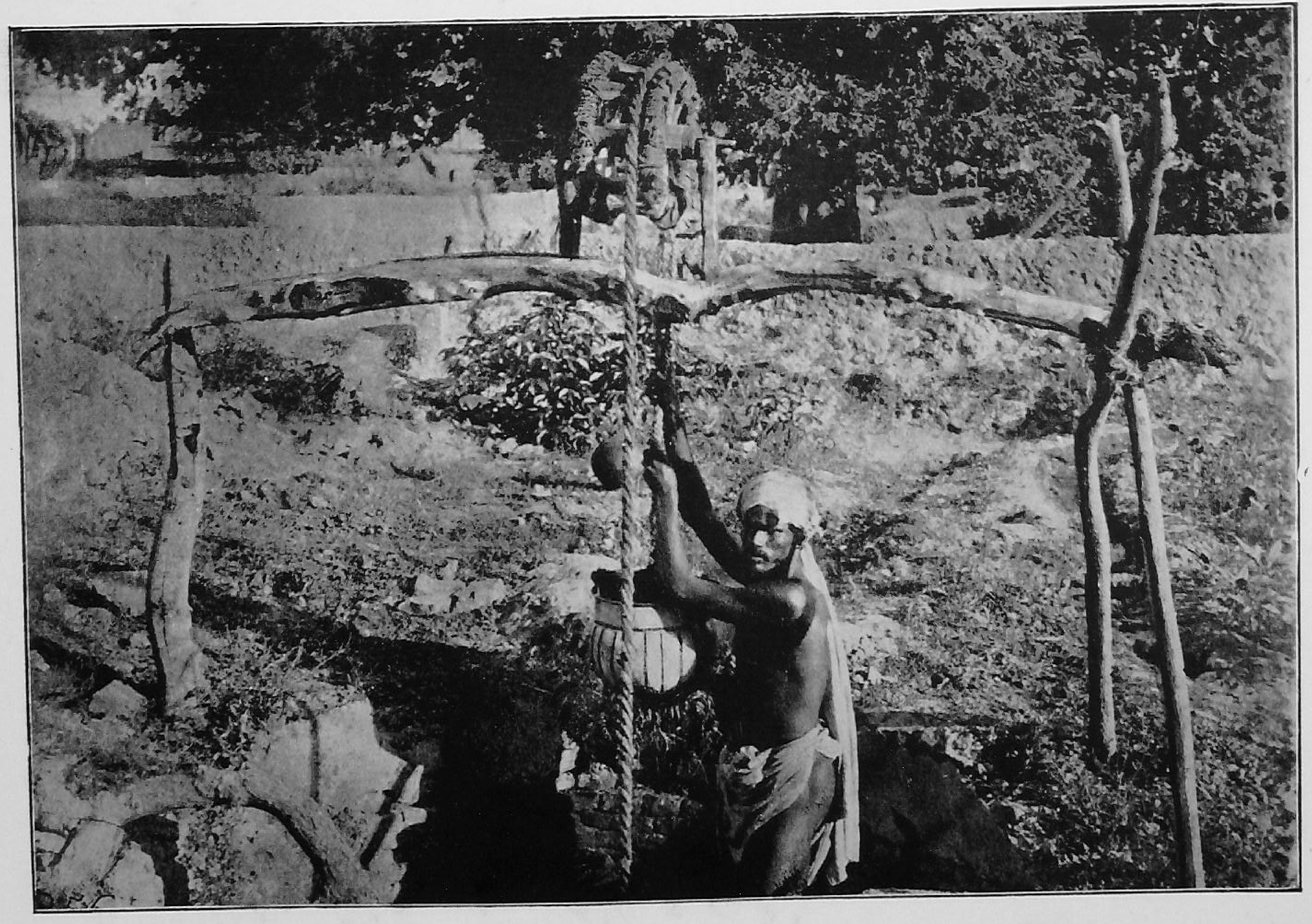


FIG. 15—Wheel lift (Chingleput).

The former is on the lines of the Persian wheel is common in many parts, and is often worked by bullock power.

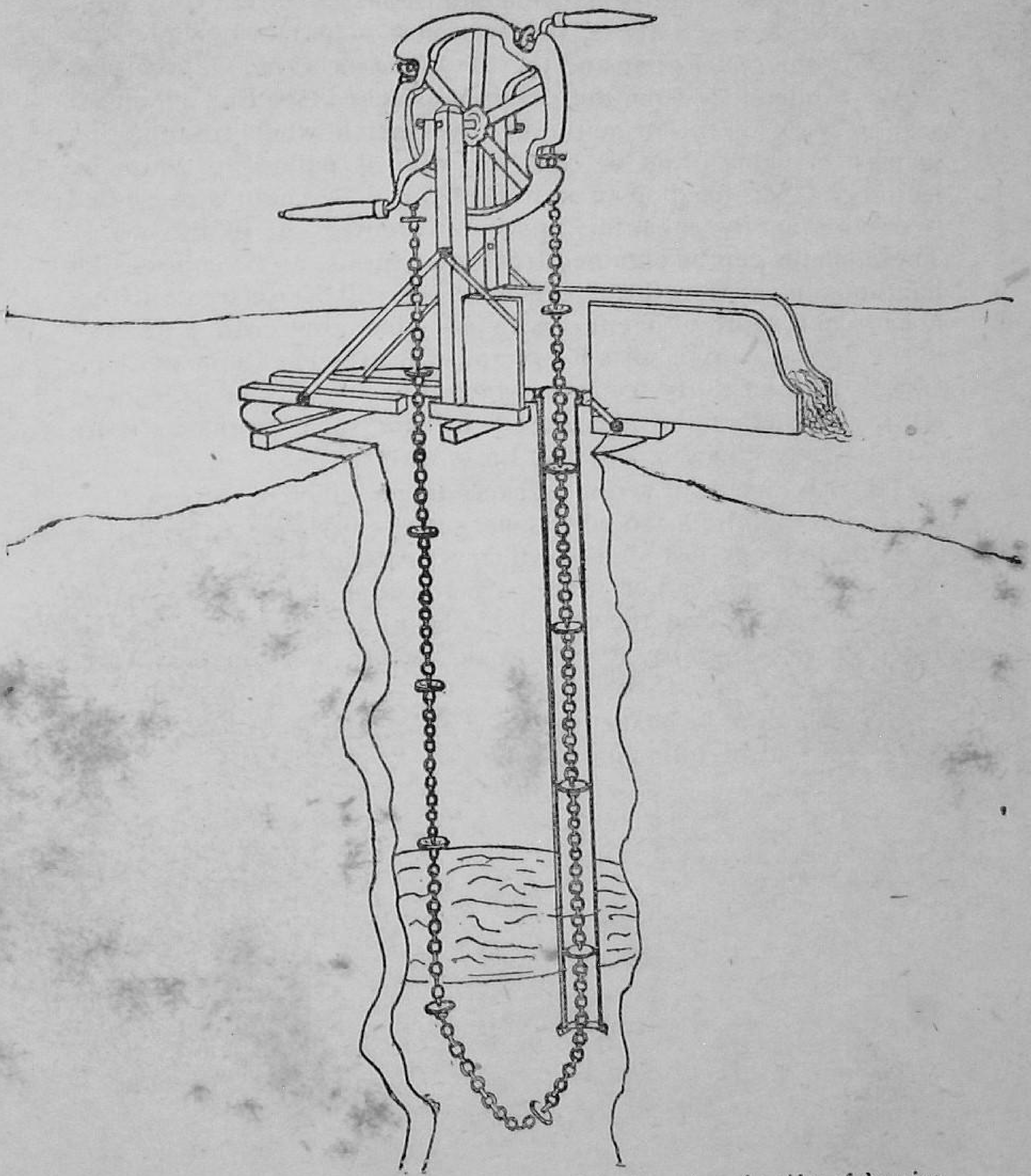


Fig. 16—Chain pump: the circular leather washers fit against the sides of the pipe and push the water up and out into the trough at the surface.

The Travancore *chakram* is rather different to most of the contrivances, hitherto considered, but the conditions are different, in that it is worked not to lift water on to the land, but to lift it off, in other words, the chakram is used to drain low-lying swamps sufficiently to take a crop of paddy therefrom. It is a paddle wheel, with twelve paddles of very neat construction, working in a slot, and made to revolve by means of the feet: the slot is provided with a shutter which can be let down before the wheel as soon as work stops, to prevent the water flowing back again.

All the above are indigenous lifts. They are in many cases partircularly efficient, but in general are rather roughly constructed, and the use of more carefully made machines has in certain conditions been advocated. Of these, the two most to be recommended are probably the *Chain pump* and the *Archimedean screw.* The former will be understood from the diagram attached (see Fig. 16) and is seen to work on the principle of the Persian wheel, except that instead of being lifted in cups, the water is pulled up a pipe by leather washers fixed on an endless chain. The chain is prevented from slipping, by engaging in special grooves cut in the wheel. These pumps can be obtained from many firms, and the prices for hand pumps run from the cheapest, which will lift 9,000 gallons per hour from a depth of five feet with a 4½-inch pipe costing Rs. 48 * to the dearest, which costs Rs. 75 and will lift 600 gallons per hour from a depth of thirty feet up a 2-inch pipe. It may be questioned however, whether the pump is efficient for such depths as there must be a considerable slip past the washers.

The Archimedean screw is exceedingly efficient for low lifts, and has been introduced with some success in Tanjore, for lifting water on to lands just above ordinary irrigation level. It consists of a cylinder, one end of which is made to dip under the surface of the water. Within the cylinder is a spiral partition, the effect of which is gradually to screw the water upwards when the cylinder is rotated. (See Fig. 17.)

This lift can be made to order through the agency of the department at the following rates:—

Length of the lift.	Approximate height in which water can be lifted.	Prices.				
		1 foot diameter.	1′ 3″ diameter.	1′ 6″ diameter.	1′ 9″ diameter.	2 feet diameter.
FT.	FT.	RS.	RS.	RS.	RS.	RS.
5	2½	22½	25	30	35	40
6	3	27	30	36	42	48
7	3½	31½	35	42	48	56
8	4	36	40	48	56	64
9	4½	40½	45	54	63	72

A 6 feet machine, 1¼′ in diameter, can be worked by one man easily. Heavier machines will require 2 to 3 men to work them. When the lift is low, say 1½′ it has been found that an Archimedean screw 6′ by 1¼′ discharges 21,000 gallons per hour (one gallon equals ·16 cubic foot). So it can irrigate one acre of land with 6 inches of water in 6½ hours.

* Taken from the catalogue of the Empire Engineering Co., Cawnpore, who were awarded a gold medal for this pump at the Allahabad Exhibition, 1911. A good pattern is also sold by M.R.Ry. C. Ramaswami Chettiyar of Tiruppattur, North Arcot.

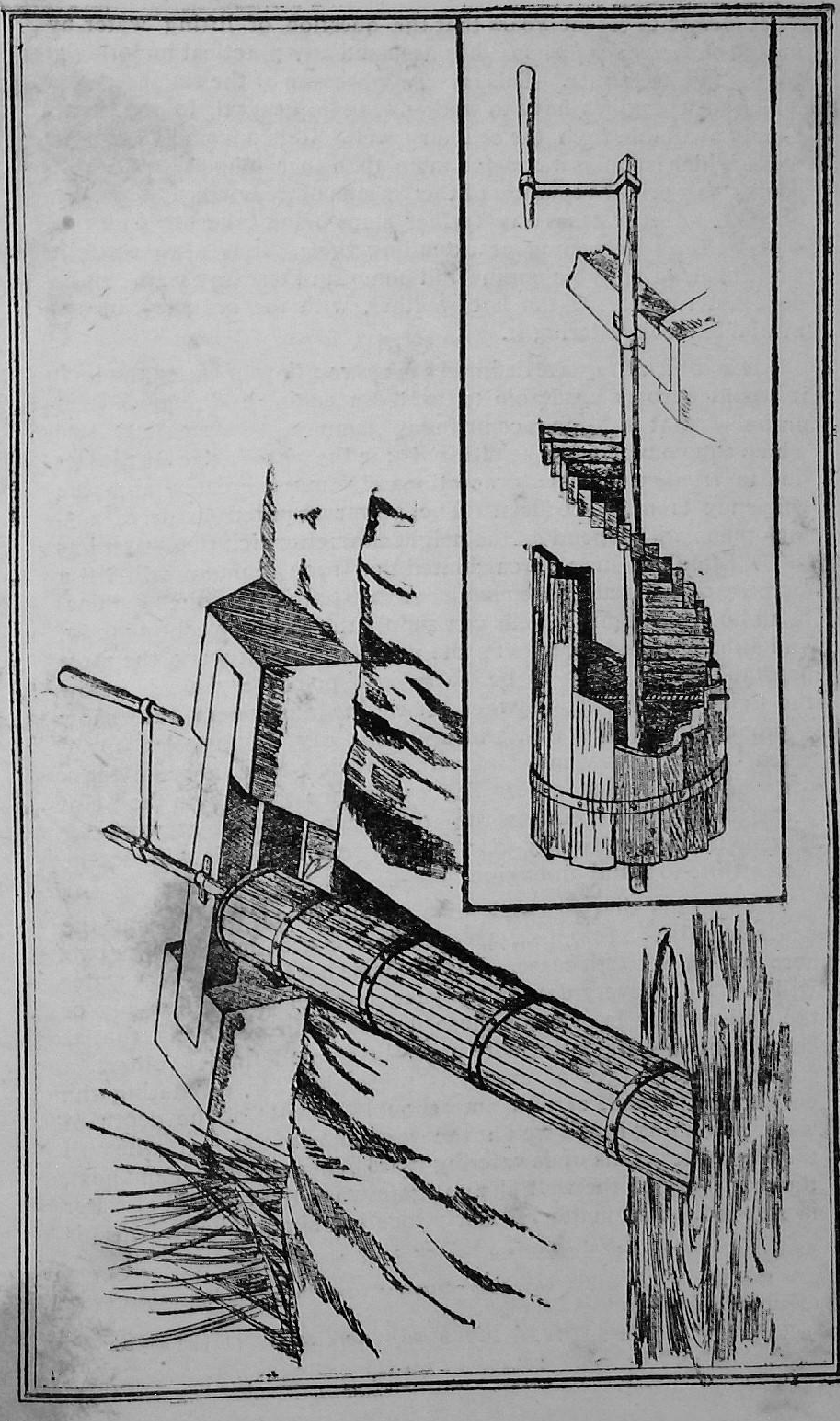


FIG. 17—Archimedean screw lift.

It is only in recent years that the question of lifting water by means of *engines and pumps** has assumed any practical importance for the Indian farmer. This is largely because of the small scale on which such engines have to work, owing in general, to the small supply available from the ordinary well. It is uncommon to find wells which supply water for more than four mhotes, though of course the primitive nature of this means of removing the water, prevents in many cases any further steps being taken to improve such wells by deepening or extending them. It is always worth while to hire a portable engine and pump, and test any well, which does not run dry in the hot weather, with the ordinary means available for dewatering it.

It is difficult to state definitely the lowest flow of water at which it would become profitable to instal an engine and pump. It is probable that a 3-inch centrifugal pump is the smallest size which can conveniently be ultilized† ; in the smaller sizes the losses due to friction become proportionately much greater, and the efficiency is much reduced. The power required to drive a 3-inch pump will depend on the height through which the water has to be lifted. It may be calculated that such a pump will lift a quantity of water at least equivalent to 220 kavalais (of fifty gallons) in an hour. Not many wells can supply the quantity continuously, and although the longer hours the installation is at work, the more profitable it is likely to be, there is a point very much below the figure named above, when an engine and pump can show a profit over the kavalai, and a pump may be installed for a much smaller inflow into the well, provided there is room for a certain amount of storage. The experience gained on the point seems to show that unless the engine can be kept at work for four hours in the twenty-four all the year round, it will not be worthwhile to instal an engine.

This means that the well must supply in 24 hours, what the engine can lift in four, i.e., 44,000 gallons or 7,260 cubic feet, or two acre inches, or 1/12th cusec. It is of course not imagined that water will be needed every day in the year, but the average supply of the well must at least reach these figures, and considering that at certain seasons water is more urgently wanted than at others, a considerable margin of excess is preferable. In estimating the capacity of a well, careful note should be made of the depth of water remaining in the well at the driest time of the year, when all the available means of dewatering it are being employed, and next, the rate at which the well fills up again when the removal of water is stopped. The matter is not altogether simple, but advice is

---

* The bulk of this article has been extracted from the published papers of A. Chatterton :—see list of books on page 61.

† In Bombay a 2½-inch pump has been found to work satisfactorily and one is in use at the Central Station, Coimbatore.

available* from the Department of Industries, who have for hire portable plants with which an actual test can be made. In any case, the chances are that the well will improve, because if it can be emptied, opportunity may be taken to deepen it, and thus probably improve the supply.

The problem is not however purely a mechanical one. From the engineering point of view, the matter is simple and the experiments carried out by Chatterton have disposed of the difficulties which were once experienced, so that the erection of a small pumping installation is a simple matter now-a-days,† and its mechanical success can be absolutely assured.

There remain, however, other aspects of the question which may be briefly considered. Firstly, an engine however simplified, remains a very complicated affair when compared with a mhote, and it needs proper care and attention. When one first sees an engine at work, it seems to run so easily and smoothly and to be so easy to start and stop, that one is tempted to overlook the fact that this very smoothness is due to the accurate adjustment and interplay of a number of parts, and that if these are allowed to become loose, or improperly lubricated, the efficiency of the engine may become seriously impaired and its life shortened. Good wages for good drivers should not therefore be grudged. No doubt a very little training will enable a cooly to run an engine, and run it satisfactorily for a time, but he will be ignorant of the proper adjustment of the parts, and may, in his ignorance, allow the engine to run in a state which will very soon wear it out. Skilled supervision is becoming every day more available, as the number of trained mechanics, from railway shops, mills, factories or industrial schools, increases, and attention may also be called to a scheme whereby any owner of an engine can, on payment of a fixed annual fee,‡ have it periodically examined.

Repairs should be carefully and promptly attended to. A worn bearing may not prevent an engine from working, but it implies loss of efficiency,—which is often not very evident to the owner, and with which the driver does not usually concern himself,—besides involving the risk of other and more serious damage. The personal attention of the driver is such a valuable asset, in the proper

---

* See Notification No. 393, dated 19th July 1913, which specifies the fees levied in such cases. The usual charge is Rs. 3 a day plus working and transport charges.

† Advice as to the suitability of a well will be given by the Department of Industries; a fee of Rs. 10 is levied for inspection. Plans and estimates will be prepared on payment of a fee not exceeding 2½ per cent of the estimated cost of the installation. The supervision of the erection of the machinery and building will be undertaken on payment of a further 2½ per cent in their estimated cost.

‡ An annual charge of Rs. 15 will insure three or more routine inspections a year, by the Department of Industries. See Notification No. 393 referred to above.

running of an engine, that it may be advisable to arrange some bonus, to be paid to him on condition that he keeps down the bill for repairs.

The installation of an engine and pump implies the expenditure of a fairly large sum of money in the actual purchase of the plant, but expenditure should not stop here. Besides the money to be spent on fitting up the engine, and housing it, the owner must be prepared to meet the cost of laying out the extra land which his well should enable him to irrigate, and to purchase the additional manure which he must use in order to get full value for his water. The number of bullocks from which he can obtain manure will be lessened, while at the same time the demand for manure will be increased. It would be well if the owner devoted every anna which he spent formerly on feeding the cattle he will now be able to sell, in the purchase of manure for his lands, in order to maintain their fertility. Care should also be taken to see that the water is not wasted. This advice may seem superfluous, but the flow of water is so much greater than the coolies are accustomed to, and is produced with apparently so little effort, that the coolies are apt to become careless, and the water is not employed as economically as if it were being lifted bucket by bucket by bullock power. It is perhaps advisable, though theoretically unsound, to divide the flow and divert it into several channels, so that each distributer shall have only the flow with which he is accustomed to deal.

It would at first sight appear that, in the force of the wind, the farmer has at his disposal a source of power which might well be utilized for lifting his all-precious water. The successful utilization of this force is however still a matter for trial and experiment, though almost certainly in suitable tracts, successful plants could be erected. The great advantage of the wind is of course its cheapness, it is free to all; the great disadvantage is its irregularity and uncertainty. For the purpose of lifting water this is a serious defect, because a stoppage of the supply of water at a critical time might lead to very serious loss.

Recourse then must be had to storage works. Were windpower to be used for crushing cotton seed, or chaffing straw, a reserve of treated material could always be kept in hand, sufficient to meet spells of calm weather such as experience showed were likely. In the case of water this storage becomes an expensive item; if the water is stored above ground it will need a strong masonry containing wall, while if below ground, it will have to be lifted again before use. The windmill might be erected on high land, where the water could be stored below ground level, but yet high enough to flow on to the lower lands, and there also would be felt the most wind, but unfortunately, there also is the least chance of finding a good well.

Windmills need careful erection and careful adjustment. It is necessary to mount the wheel carrying the vanes at some height from the ground, in order to get clear of houses and trees and catch all the wind possible, and this necessitates a tower, usually made of trussed steel. The size of the wheel also governs the power which the windmill will develop.

The main difficulty seems to be that the power of the mill varies so largely with the wind, being proportionate to something more than the square of the wind velocity. On the other hand, since the amount of water lifted depends on the velocity of rotation of the wheel, which in turn varies *directly* with the wind velocity, there is obviously a loss of energy at high wind velocities.

Aermotors, as the more modern types of windmill are called, have been tested by Chatterton, who has pronounced favourably on their chances of success, provided certain conditions are observed. He shows that the motion of the air in certain places is certainly sufficient for the purpose, but criticises the cheap American aermoter, as being too flimsily constructed to be of much use. He considers that a 16 feet wheel, on a 40 feet tower, would be sufficient for most places; the wheel should be geared down to the pump shaft, in the ratio of 3 to 1 and the pump should be from 10 to 20 inches in diameter, depending on the lift, and fitted with mechanism to vary the length of the stroke automatically with the strength of the wind. In order to ensure the safety of the wheel, it should be fitted with a governor, to throw the wheel out of the wind, as soon as its velocity exceeds thirty miles an hour. For such a plant he considers it would be practicable to pay Rs. 1,500 to 2,000.

Before leaving the subject of lifting water by means of power, we may see what lessons can be learnt from some of the installations which have been erected. The largest is that erected on the Divi Island in the Kistna district, with a capacity of over 570 cusecs. The installation consists of eight Diesel oil-engines, each of 160 brake horse-power and each driving a 39-inch centrifugal pump. The area irrigated by this installation is at present 26,000 acres, but it is designed ultimately to irrigate 45,000 to 50,000 acres. The source of supply is here obviously not a well, but the Kistna river itself, and a number of other similar but smaller private installations have since been erected to take the water of rivers which at present flows uselessly to the sea. In some cases, the engine may be erected, as in an instance on the Cauvery, to supplement other sources of supply, or as an insurance against partial or total failure of the ordinary sources. In such cases the river bank (padugai) lands are fertile and a perennial crop, such as plantains, which can be grown only with an assured supply, brings in very profitable returns.

4. Cost of lifting water.—Experiments were carried out some years ago at Saidapet to determine the cost of lifting water by cattle, and the conclusion was reached that 4,000 cubic feet of water could be lifted one foot for one anna. here has been a considerable increase in the rates for cattle hire since then, and this figure today would certainly have to be raised. If we take the hire of a pair of bullocks with driver as one rupee a day, we may suppose that they lift (50 × 40 × 8) 16,000 gallons in a day's work of eight hours, or 1,000 gallons for an anna. If the depth of the well be taken as 25 feet, the amount is 25,000 gallons lifted one foot for one anna or 4,000 cubic feet. This calculation takes no account of the cost of the bucket and the rope, and it would not be possible to hire cattle at this rate for continuous mhote work.

An engine will, in anything like favourable circumstances, lift very much more than this for the same sum. The working charges of an engine at one of the College wells have been carefully kept, and are as under:—

Monthly—	RS.	A.	P.
Liquid fuel	30	0	0
Kerosene-oil	4	0	0
Lubricating-oil	2	0	0
Waste: stores, etc.	1	0	0
Driver	10	0	0
Depreciation and interest at 10 per cent and repairs 5 per cent	37	0	0
	84	0	0

Liquid fuel costs in Coimbatore between Rs. 60 and 70 a ton, with cartage from the station extra. A ton contains about 250 gallons, so that the cost works out slightly over 4 * annas a gallon.

The engine runs about 160 hours a month at ¾ gallon of fuel an hour. These hours should be increased, when the cost of running per unit would be much reduced. On the other hand, the driver at Rs. 10 is cheap: he is a farm-trained hand and works under fairly close expert supervision. The cost of the installation has been taken at Rs. 2,960.

The pump may be supposed to lift 18,000 gallons to a height of 25 feet each hour, or say 72,000 cubic feet to a height of one foot: then the number of feet lifted 1 foot for 1 anna $= \frac{72,000 \times 160}{84 \times 16}$ or 8,500. This figure is on the low side, and far more favourable results could be obtained, if the engine were run for longer hours.

---

* The price has increased since Mr. Chatterton first wrote.

Another way of expressing the cost of lifting water is to use the acre-foot, i.e., the quantity of water needed to cover an acre of land to a depth of one foot. This is equal to 43,560 cubic feet or 272,250 gallons. On the above figures for the cost of lifting by bullock power and by the engine, the cost would work out to 10·8 annas and 5·2 annas, respectively, the lift being one foot in each case.

5. **The duty and use of water.**—The duty of water is a most important term in all questions of irrigation and is a measure of the amount of water which is necessary for crop production. Up to a certain point, an increase in the amount of water supplied will mean an increase in the crop produced, but the law of diminishing returns prevents the *economical* use of more than a certain quantity of water, which however varies very largely with the conditions in which the crop is grown.

Before considering the duty of irrigation water, and the means under the farmer's control for making the most economical use of the water at his disposal, it will be as well to see the different ways in which irrigation water may be used up. There is first a considerable loss in conveying the water from the source at which it is available, to the point at which it is delivered to the field. This loss occurs by seepage in the channel along which it travels and by evaporation from the surface. Much depends on the care with which the channel is constructed; if the gradient is insufficient the rate of flow will be checked, and the losses will be increased, while a too rapid fall may lead to scouring in the bed of the channel. The losses from seepage will be largely increased if the soil is porous, and will be correspondingly decreased if the soil is dense, while the losses from evaporation will largely depend on the nature of the climate, and the time of year during which irrigation is proceeding. Experiments at Cawnpore* have been carried out to determine with some accuracy, what these losses may amount to, and are arranged in the following manner. Water is first raised into two cisterns, from which it passes along channels 150 yards in length, to a second pair of cisterns: the amount of water lost on the way being determind by measuring the amount of water passing through each pair of cisterns. The object of having a double system is to determine in one instance the loss in a channel used regularly, and in the other the loss in a channel used for the first time after a prolonged drought. The results of six years' experiments show that in such conditions, the average loss is from 15 per cent to 20 per cent, with extremes of 6 per cent and 30 per cent. The figures are rather astonishing, and enable some idea to be formed of the losses which may occur in the larger canals many miles in length. The matter is of interest to the farmer

* Cawnpore Station Reports.

who sometimes sends the water he has so carefully lifted from a deep well, a considerable distance along an earthen channel to the field he is irrigating. Such seepage is often utilized by the coconuts or other trees he plants along the sides of the channel (see Fig. 18), but economy would probably be effected by lining such channels and making them water-tight, irrigating the trees directly when necessary. A cheap form of water-tight channel has yet to be found, and would certainly prove a great boon.

When the water has arrived at the field, it is used up in three ways : it may (*a*) sink into the soil, be absorbed by the plant and finally transpired through the leaves, or (*b*) it may be evaporated directly from the surface of the soil, and serve no useful purpose save that of rendering the air moist and thus checking transpiration, or (*c*) it may soak deeply into the soil and pass away into the subsoil water, beyond the reach of the crop. The two latter involve practically a dead loss to the farmer, and though they are partly unavoidable, they may be minimized by the care and skill with which the water is applied.

These losses and consequently the duty of the water will also depend on a number of other factors beyond the control of the agriculturist, and these may be considered first. It is a well known fact that certain crops require more water than others, and the duty of water will consequently depend on the crop grown. These differences are due to the nature of the plant, that is, the rate at which transpiration must proceed to maintain the plants' health ; to the habit of the plant,—certain crops will shade the land more than others, and will thus check evaporation from the soil, with a consequent economy in the water used ; and to its period of growth. The root system again excercises considerable influence on the use made of water by the plant, since a shallow rooted crop will require more water than a deeper rooted one ; because it will have to be irrigated more often, though it is probably true that the time taken for the water to soak into the subsoil where the deeper roots are found, may result in an actually greater proportionate loss by evaporation. Light waterings for instance might never reach a deep root at all.

An instance of the difference which may occur between two crops growing under approximately similar conditions, may be seen in the amount of water needed for wheat and Cambodia cotton and Coimbatore. The former is a 3½-month crop, being sown in late November and reaped in late February or early March ; it requires ordinarily 8·2* irrigations : Cambodia, from September to April, needs only 2·1 on the average. Paddy may be cited as a crop which requires an excessive amount of water, owing to the conditions under which it is grown.

---

* Average of four years.

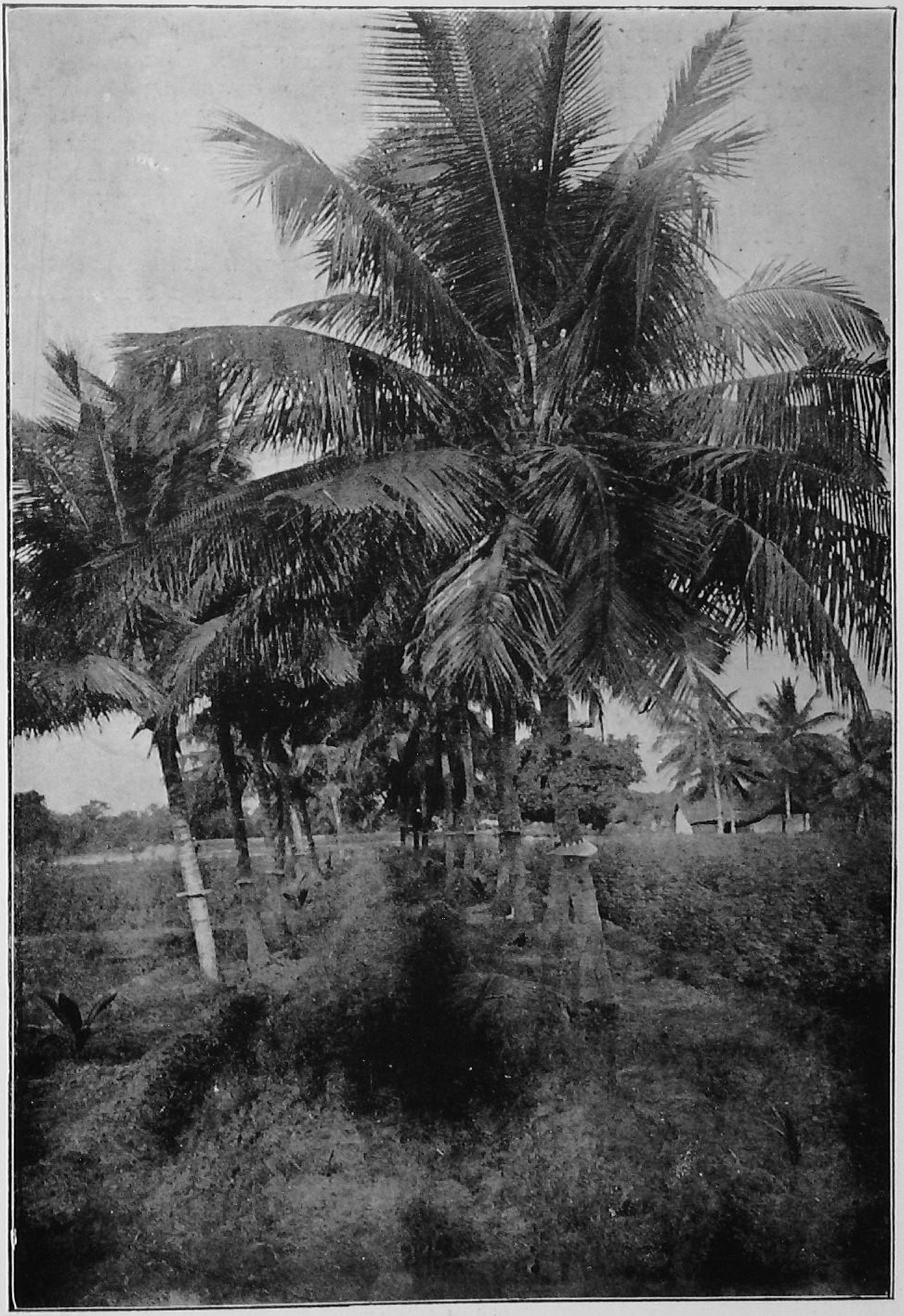


FIG. 18—Coconuts planted on either side of water channel taking advantage of seepage.

The climate is an equally important factor in deciding the use which can be made of a given quantity of water. As in moist climates no irrigation is needed at all, so it follows that even in places where irrigation is a necessity, the damper the air, the less the loss by evaporation and transpiration, and consequently the greater the duty of water. Evaporation is also checked by low temperature, and the high duty obtained in the irrigation of wheat in Upper India is partly due to the low temperatures prevailing when this crop is grown. The effect of wind in increasing evaporation may also be noticed.

The last important factor which affects the duty of water is the nature of the soil and the subsoil. In a sandy soil the water is quickly absorbed, but on the other hand, the soil does not retain the water, which, if applied too liberally, will pass beyond the reach of the crop roots and be lost. An ideal soil would be a layer of sand overlaying a more retentive soil, and something of this sort is to be seen at Hagari (Bellary district) where the blown sand from the river bed, overlies alluvial or cotton soil of greater retentiveness.

The nature of the soil also exercises a considerable influence on the root formation of the crop ; lack of adequate drainage keeps the root system near the surface, so that it may happen, that, though the subsoil is saturated with moisture, irrigation becomes essential. These factors, the soil, the climate and the crop grown affect the duty of water and largely determine the area which can be irrigated from a given source. Besides these, the skill of the user must be taken into consideration, since carelessness in apylying the water to the crop may lead to considerable loss. Such considerations, as the frequency of application, the amount applied at a time, and the method of distributing the water will be more fully discussed later, but all must be taken into account when the duty of water is under discussion.

Accurate figures of the amount of water used in irrigation are difficult to obtain, in spite of the importance of the question in South India, though there are certain general figures which are of value.

There are two ways in which the duty of water may be expressed, either as the area which a constant flow will irrigate, or the amount of water needed at definite intervals of the growth of the crop. The first is the method commonly adopted and is expressed as *the number of acres which can be successfully watered by a flow of 1 cubic foot per second*, an amount which is briefly called a 'cusec'* or in America 'a second foot.' In the other method the measure used is the inch, and the duty is expressed usually as

---

* It is convenient to remember that 1 cusec gives 2 acre-feet approximately in 24 hours.

the number of inches required every ten days. The 'Duty' is considered to represent the amount actually used by skilled agriculturists, and is somewhere between the *minimum* which will just keep the plant alive, and the *maximum* which makes the ground so wet that the yield is reduced.

To find the amount of water actually applied to the crop, we must know the base, i.e., the period over which the duty is reckoned. Thus, if we say that for rice cultivation the duty is fifty acres, we shall have to calculate in the following way to arrive at the actual quantity used : the base may be taken as six months.

1"	No. of c.ft. per	second
1×60	Do.	minute
$1 \times 60 \times 60$	Do.	hour
$1 \times 60 \times 60 \times 24$	Do.	day
$1 \times 60 \times 60 \times 24 \times 30$	Do.	month
$1 \times 60 \times 60 \times 24 \times 30 \times 6$	Do.	six months

i.e., the base=15,552,000

This figure must be divided by 50 to give the amount delivered to every acre.

$$15,552,000 \div 50 = 311,060 \text{ c.ft.}$$

Divide this again by the number of square feet in an acre to get the depth of water in feet.

$$\frac{311,060}{43,560} = 7{\cdot}13 \text{ feet.}$$

To express as the number of inches given every ten days to each acre is similar.

$$\frac{1 \times 60 \times 60 \times 24 \times 10 \times 12}{50 \times 43,560} = 4{\cdot}7 \text{ inches.}$$

This quantity if given every ten days for six months will be found equal to the 7·13 feet given above. The reverse calculation presents no difficulty, i.e., if you are given the depth and the interval of each watering you can find the duty in acres to the cusec. For instance, in the above example, the crop received 4·7 inches of water every ten days. Each acre therefore in ten days gets

$$\frac{4{\cdot}7}{12} \times 43,560 \text{ c.ft.} = 17,061 \text{ c.ft.}$$

Now in ten days the discharge of a cusec is

$$60 \times 60 \times 24 \times 10 = 864,000 \text{ c.ft.}$$

which at the rate shown above is sufficient for

$$864,000 \div 17,061 = 50 \text{ acres.}$$

This duty, i.e., fifty acres to the cusec, is one which may be accepted as a very rough average for the cultivation of wet paddy under the ordinary irrigation tanks. In such systems, owing to improper management and probably the very large loss which occurs from evaporation, there is considerable waste of water, besides which more water is actually used than is necessary,

with the result that the duty is low. More accurate figures are available from the large canal systems, where a very efficient system of measurements is in force, and where an average duty of 100 may be reached and at times exceeded. Much of the trouble which occasionally occurs, especially at the beginning of the season, is due to the high demand for water at particular seasons, e. g., at the time of *transplanting, in much the same way that in Bengal, the universal demand for water just before the harvest, taxes the supply channels to their utmost.

These figures, it must again be emphasized are only rough approximations, and convey little without a knowledge of the circumstances. The duty at the head of a canal will be very different from that of the water entering the field: the point has been discussed before, but measurements in the Ganges canal have shown that 1 cusec entering the canal becomes ·85 at the distributary and ·56 where it enters the field. Paddy is the crop for which water is ordinarily applied in Madras and it is therefore the crop of the most interest, but useful information may be gained from a consideration of the duty of water obtained in other parts and with other crops. The average duty of the canals of Upper India is given as 267. This is largely for the cold weather irrigation of such crops as wheat which occupy the ground for four months, and receive four waterings of about three inches each. The duty may accordingly be worked out as follows :—

Amount of water available = $60 \times 60 \times 24 \times 120$ cubic feet. Amount required per acre (area in square feet into depth of water in feet) 43,560 into 1 cubic foot. Therefore area irrigable $= \frac{60 \times 60 \times 24 \times 120}{43{,}560}$ or 238 acres. This is lower than the average stated above, but may be increased by rains which are expected to fall during the growth of the crop. The highest efficiency reached anywhere is probably in Southern California† where a duty of 500 is reached, equivalent to 4·76 inches every hundred days. The water is applied to citrus orchards and needless to say every precaution is taken to ensure economy, which is assisted by the depth and fertility of the soil.

As of interest in this connexion, a table is given below which shows some of the results of irrigation experiments conducted at

---

* An interesting note has recently been published showing the amount of water actually needed in the Undi canal in the Gōdāvari system. (P. W. Circular Memorandum, 945 E., dated 22nd June 1915.) It was found that a duty of 70 was suitable and sufficient, that is, that a more copious supply would not have accelerated planting, the rate of planting being determined by other factors, e. g., cattle, coolies, or seedlings. For the period of four weeks during which transplanting was in progress, 16 to 18 inches of water, including rain, was found sufficient for transplanting and for maintaining the crop as soon as transplanted. For this latter purpose, an allowance of ¼ inch depth, in 24 hours (equal to a duty of 95·2) is made for half the total area under consideration.

† Lift irrigation: Chatterton, page 341.

Coimbatore and at Cawnpore, as to the amount of water necessary for certain crops :—

Name of crop.	Duration of irrigation.	Cubic feet of water required per acre.	Total inches supplied exclusive of rainfall.	Duty of water.
	Coimbatore.			
	DAYS.		INCHES.	
* Ragi ; (Ridges) average of 4 years.	90	35,000	9·6	222
Ragi ; (Beds) average of 4 years ...	90	42,500	11·7	182
Wheat ; average of 5 years ...	112	62,000	17·4	156
Hot weather sorghum ; (Ridges) ...	105	33,000	9·0	275
Hot weather sorghum ; (Beds) average of 5 years.	105	36,000	9·9	252
	Cawnpore.†			
Pounda cane	292	154,200	42·4	163
Potatoes	150	42,700	11·7	303

6. Use of water.—If the ryot is asked how much water his crop needs, he will generally reply by stating either the total number of waterings it requires, or that it requires watering every so many days, depending of course on the amount of rain received during the period. This raises two points about irrigation methods, namely, the frequency and the amount of the waterings which will give the best results. It may be laid down generally that as much water should be applied to the soil at each watering as the crop will tolerate, without suffering. This is because frequent waterings mean an increase in the labour bill, a greater loss in seepage in the supply channels which lose less water when they are thoroughly soaked, and a higher proportionate loss in evaporation. There is however a limit to the amount which can be applied in one watering, as very heavy waterings imply practical difficulties in the construction of higher bunds, or deeper furrows, and the risk of damage to the crop. It has as a matter of fact been found that except for special crops, a 'watering' is a fairly uniform amount. It is fixed principally by the time taken to flood the area of the plots into which the land is divided, or the length of the furrows into which it has been laid. The smaller the unit in either case, the less the amount of the 'watering,' because the shorter the time taken to wet the area. In a very large plot or a very long furrow, a considerable portion of the water will be absorbed by the area near where the water is admitted, where the water has already

* Ragi : *Eleusine coracana.*

† The figures on which these calculations are based are taken from the Cawnpore Agricultural Station Report for the year ending June 1912. They are the averages of six years' experiment under conditions which seem more variable than in Madras. The duration of irrigation, e.g., in the case of Pounda cane varies from 4½ months in 1906–07 to 12 months in 1908–09.

covered the surface. Very small plots have however practical disadvantages, in that they waste space and entail more trouble in their construction, and we find that the farmer has from long experience struck a fair balance between these two opposing factors. The rate at which the water is admitted a third controlling factor of great importance, and the exiguous flow from a well from which a single man is baling, will usually be led into very small beds, while with canal irrigation for 'garden' crops, the plots will be much larger. It is worth noting that experience has very definitely fixed the area of the plots in the Punjab under canal irrigation, each being 110 feet × 55 feet.

With these variations, it may be stated that an average 'watering' from a well will be about two inches; a heavy watering will be three inches: a light watering such as the sprout irrigation given, e.g., to transplanted ragi may be only 1½ inches or less. We may calculate a watering however in another way. Let us suppose that a mhote can irrigate a quarter of an acre a day. We may take as average figures, that the mhote bucket contains fifty gallons, that forty buckets are lifted per hour, and that the man actually works at the mhote for eight hours. The total amount lifted will thus be $40 \times 50 \times 8 \times \cdot 1605$ c.ft. per day.

This irrigates a quarter of an acre: i.e., $\frac{43{,}560}{4}$ sq.ft. The depth of water is thus (in inches):—

$$\frac{40 \times 50 \times 8 \times \cdot 1605 \times 4 \times 12}{43{,}560} = 2 \cdot 36 \text{ inches.}$$

The following table has been extracted from the records available and gives a rough idea of the amount given at each watering under ordinary conditions, while the frequency of watering is also shown. There is a markable similarity in the amount applied at each watering:—

Crop.	Average duration of growth (or irrigation).	Maximum number of waterings.	Minimum number of waterings.	Average number of waterings.	Average depth of a watering.	Average interval between waterings.
Coimbatore.						
	DAYS.				INCHES.	DAYS.
Ragi (planted in ridges)	90	6	3	4·75	2·02	19
Ragi (planted in beds)	90	6	3	4·75	2·46	19
Hot weather sorghum (beds) ..	105	5	3	3·6	2·5	29
Wheat	112	8	5	6·2	2·8	18
Cawnpore.						
Pounda cane	292	24	9	17·0	2·5	17
Potatoes	150	8	4	6·0	1·95	25

Wherever irrigation is practised, the methods used to secure the distribution of water in the field to the growing crop will be found to differ. Many of these differences are differences of detail, and most systems adopted will be found to fall into one or other of the following four groups :—

(*a*) Sprinkling or pouring.
(*b*) Flooding.
(*c*) Furrow irrigation.
(*d*) Underground irrigation.

We may consider these more in detail.

Irrigation by sprinkling or pouring.

The first system is well exemplified in the method by which the ordinary flower garden is usually irrigated: the water is brought in cans or in chatties and poured on to the pots or beds in which the flowers are growing. At first sight, and especially when a rosecan is used, this might be thought the most natural method of irrigation in that it most closely simulates the natural rainfall. This however is not the case, and it is probably the most wasteful and least satisfactory. It cannot be used on any large scale, as the cost either of hand labour, or the machinery which might be installed to take its place would be prohibitive. Further if the applications are made light to avoid compacting the soil, the loss from evaporation will be proportionately greater. It must be remembered that when rain falls, the air is necessarily moistened, and evaporation with the cloudy sky which accompanies rain, is very considerably reduced, while at the time of artificial sprinkling, the conditions may be very favourable for rapid evaporation—it is not uncommon in gardens to find that the leaves of plants thus watered are scorched, owing to the concentration of the sun's rays by the drops of water formed on the leaf.

This method is accordingly seen but seldom in agricultural practice. Tobacco seed-beds are generally sprinkled, and other seed-beds may also be watered in this way. The paddy seed-beds raised in the sand ridge at Bāpatla are regularly watered from pots, the water being lifted from a shallow well dug to a depth of a few feet in a corner of the field; the succeeding groundnut crop is also watered in this way. The curious method of watering ragi in parts of Ganjām may also be noticed: here the water is led through the field in the usual channels, which widen at intervals into small circular pools, from which the water is splashed at intervals by a wooden shovel. (See Fig. 19.)

It may be remarked that here, as at Bāpatla, the soil is open and porous in its nature, and such conditions would obviously offer the best opportunities for this system.

A similar method is used for moistening the ground before harvesting irrigated groundnuts. In Java, canes are irrigated by splashing, the water being scooped out of parallel trenches and thrown on each side.

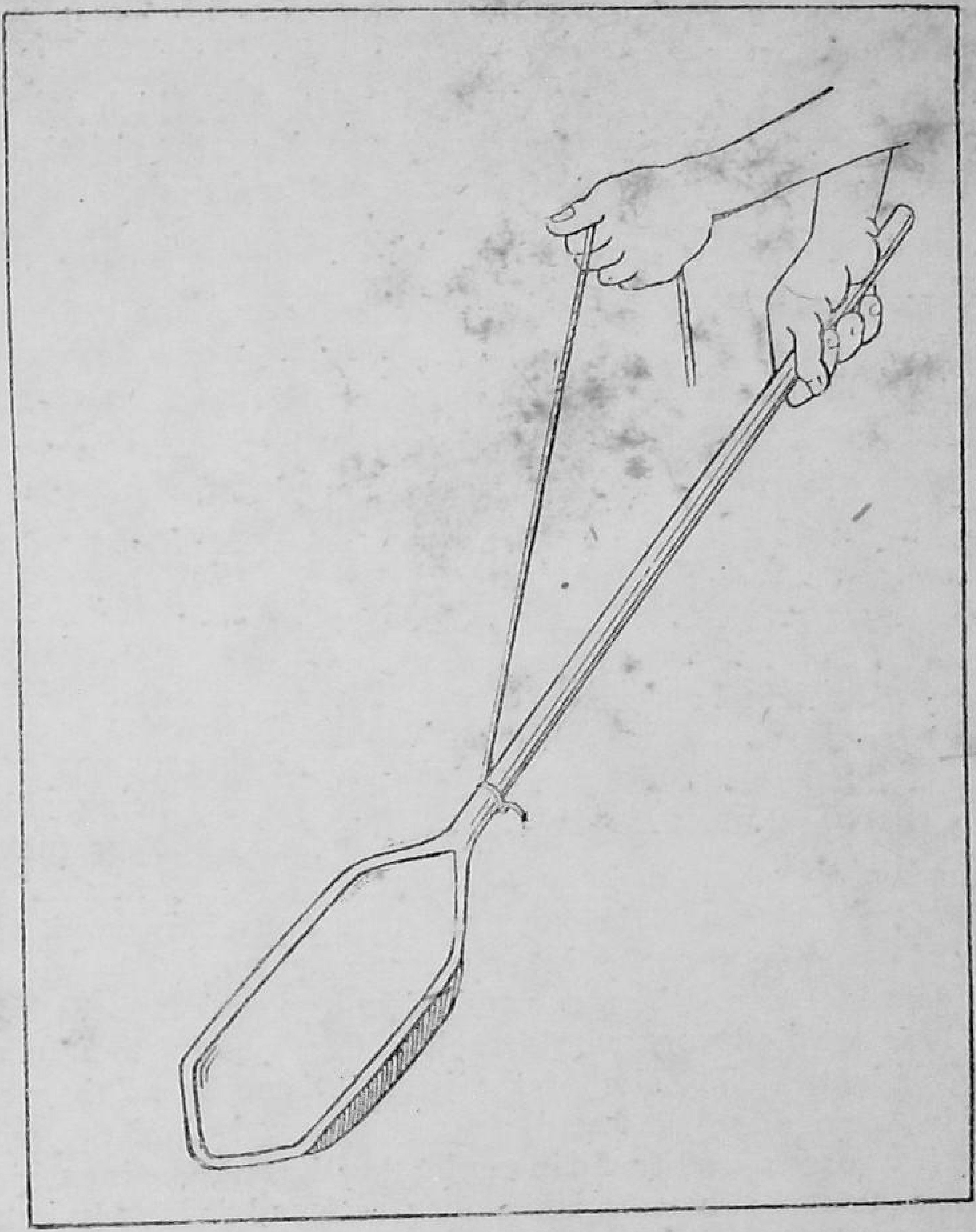


FIG. 19.—Hand shovel for distributing water (Ganjām).

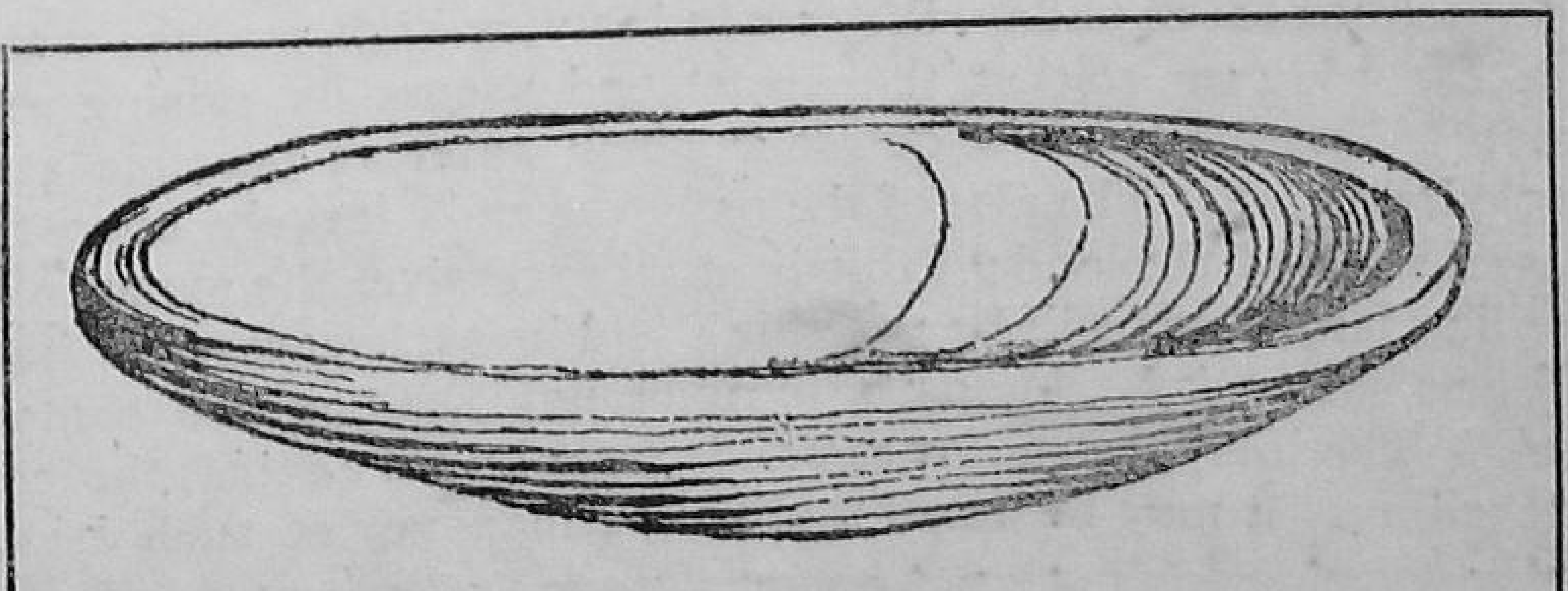


FIG. 20—Wooden scoop for splashing water in betel vine cultivation.

Mention may finally be made of the splashing by which betel gardens are usually irrigated, a flat wooden scoop being used for the purpose (see Fig. 20), and the hand watering which tobacco and chilli seedlings receive when first planted out, the object here being the careful application of water to each individual plant.

Irrigation by flooding.

In this system, the water is delivered at one spot and is allowed to spread itself by the force of gravity in the form of a layer over the surface of the soil. This layer may be stationary or may be moving. The latter system, inasmuch as it is more suitable for light irrigations, and not for the heavy soakings which are generally needed in this country, is not generally practised, and may be briefly dismissed by explaining that water is allowed to pass slowly over the land until the required degree of saturation is reached. The velocity of the water must not be allowed to become too great, or the land will suffer from scouring, and the general procedure is to grade the land to a gentle slope, and allow the water to overflow from furrows laid out almost exactly along the contour lines (and thus nearly level from end to end) the water being either turned off when necessary, or the excess caught by a lower furrow and the process repeated.

The second system is the one much more commonly used, and consists in leading the water into closed areas bounded by ridges or bunds, which check the water and allow it to soak into the soil. Even here we find very considerable differences in the actual methods adopted. The size of the beds (or checks as they are called in America), will be found to vary very largely from the small beds a few yards square found in gardens, to the large beds running sometimes to over two acres, which may be found in paddy cultivation. Again the small beds into which garden land is laid out, are usually only temporary, while the beds in which paddy is grown are permanent, and the bunds are not ploughed down. (See Fig. 21.)

These differences are correlated with differences in the demand of the crop for water and the method in which this demand can be met. In the case of paddy, the demand is very high, and the water is received in turn, so that the owner endeavours by raising and strengthening his bunds to obtain as much water as possible at a single irrigation. The size of the beds depends largely upon the natural slope of the land; if this is at all excessive, the expense of levelling large beds will be very high and in such cases the beds will be small and the bunds will run roughly along the contour lines.* The loss of area due to bunds must be set against the cost of levelling. It may be noted that the permanency of such bunds

* A good illustration of this is given in Willis· Agriculture in the Tropics, plate I, page 40.

FIG. 21—To illustrate irrigation by flooding (South Kanara).

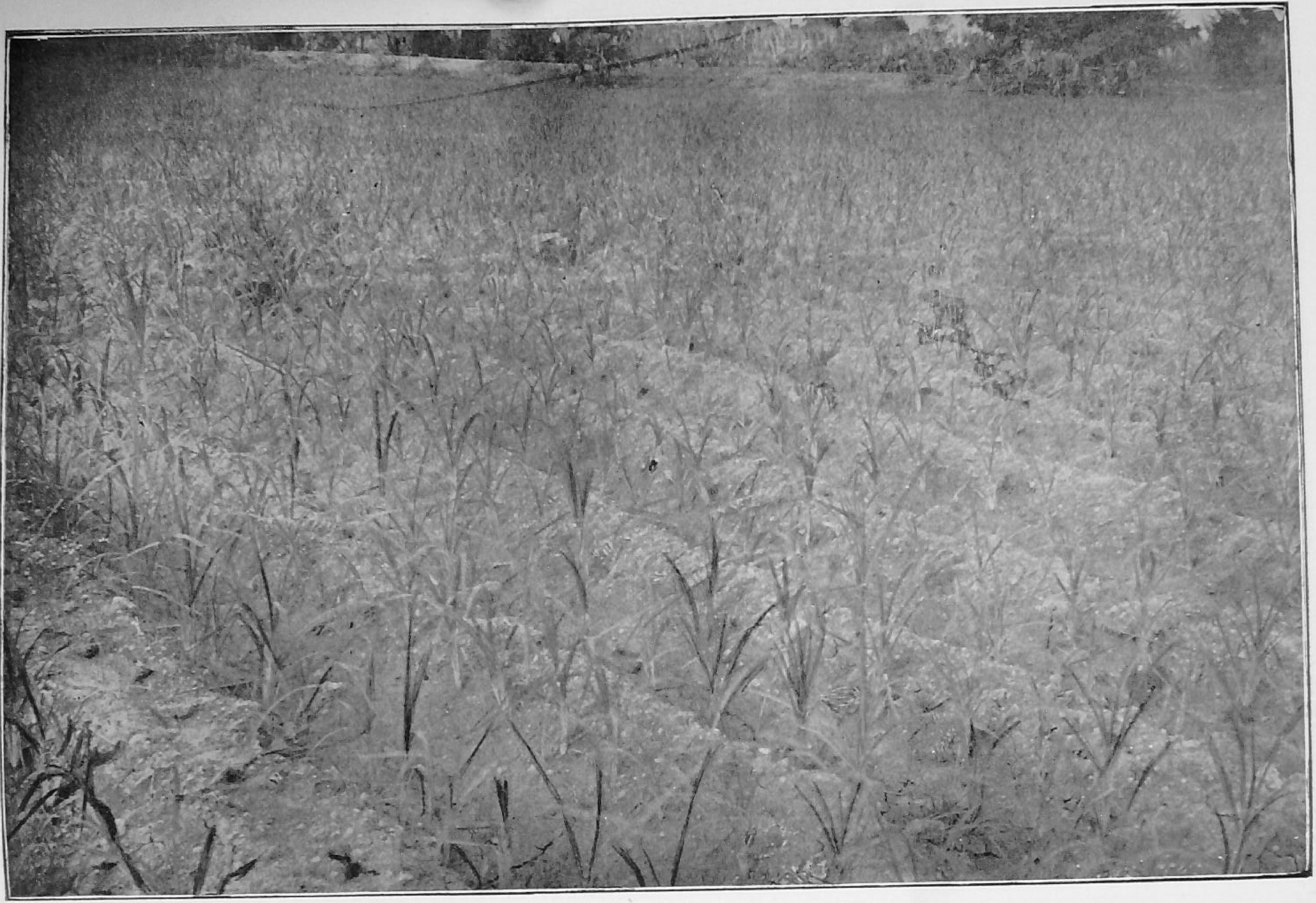


FIG. 22—Irrigation by furrows.

proves an insuperable obstacle to the use of any modern ploughs or harvesting machinery.

In irrigating garden land from wells, we are dealing with a very different state of things. The supply is small, the owner is interested in using it as economically as possible, and it is entirely under his own control. Here the beds are small, because it is impossible to irrigate a large bed evenly with a small flow, while their small size makes them cheap because much permanent levelling has not to be done to the field: all that is wanted is to shape each bed roughly level with the mamuti as the water is let in. It will frequently be noticed that where four mhotes are at work together, the flow is divided, in order to lead the water on gently, and allow the distributors to level the beds as irrigation proceeds.

Paddy irrigated from wells is usually grown in small fields or beds, and in order to prevent the loss from seepage a double bund is sometimes made, the inner one being made of puddled soil which is kept moist and smoothed by hand when cracks appear in it.

A disadvantage of the flooding system, especially in heavy soils, is that the penetration of the water may be very slow owing to the resistance of the air imprisoned below it, but in the case of paddy this does not hold, as the land normally never becomes dry, while with the small beds mentioned above the air has a chance of escaping at the sides.

Irrigation by means of furrows.

In this system of irrigation, water is not spread over the whole area in the form of a thin layer, but is allowed only to run in miniature channels or furrows, from which the water can soak in all directions and supply the needs of the plants growing in the spaces between. (See Fig. 22.)

On theoretical grounds, this system would seem to offer many advantages. There is no difficulty about the penetration of the water, since the displaced air can easily make its way upwards to the surface on either side. The loss of evaporation will be much reduced owing to the small surface exposed, as also to the fact that this surface is below the level of the ground. Further the surface wetted being but a small proportion of the total, the surface soil is not so compacted as is the case when the water is poured over the whole surface.

In spite of these advantages, we do not find the 'furrow' system of irrigation so widely adopted as might be expected, this being perhaps due to the fact that unless the furrows are made deep, which is laborious, or frequent—and then they occupy a good deal of space—it is not easy to apply very heavy waterings in this way. Moreover, furrow irrigation, if it is to be properly done needs a knowledge of levels, and an ability to utilize this

in laying out the land, knowledge which may outrun the farmer's intelligence or energy. Reference may be made to the figures in the tables on pages 32 and 33, which show clearly the economy of water which may be effected by the adoption of this system.

Just as in the case of irrigation by flooding so the water let into the furrows may be either stationary or moving, and again we find that general preference is given to the former, the water being passed into comparatively short furrows which are roughly level from end to end: the furrows when filled being closed, and the water slowly allowed to soak in. If the water is to be left to soak into the furrows, they cannot be very long, as it would be difficult to ensure them being even approximately level from end to end, and if not, the water would be applied unevenly: in any case by laying the furrows along the contour lines, the ideal of a perfectly level furrow will be more nearly reached, and the longer the furrow, the less the land wasted in cross bunds, and the less the labour required to distribute the water. If the moving water system is adopted, the furrows must be given a slope, so that the water may pass evenly down the furrow, soaking in as it goes, and being diverted at a point which experience has shown will leave sufficient water just to reach the bottom end of the furrow. King* mentions the irrigation of potatoes by furrows 360 yards long, the operators dividing the flow between a number of furrows, so that the water could run into them all night, and just reach the far end of the furrow when they returned next morning.

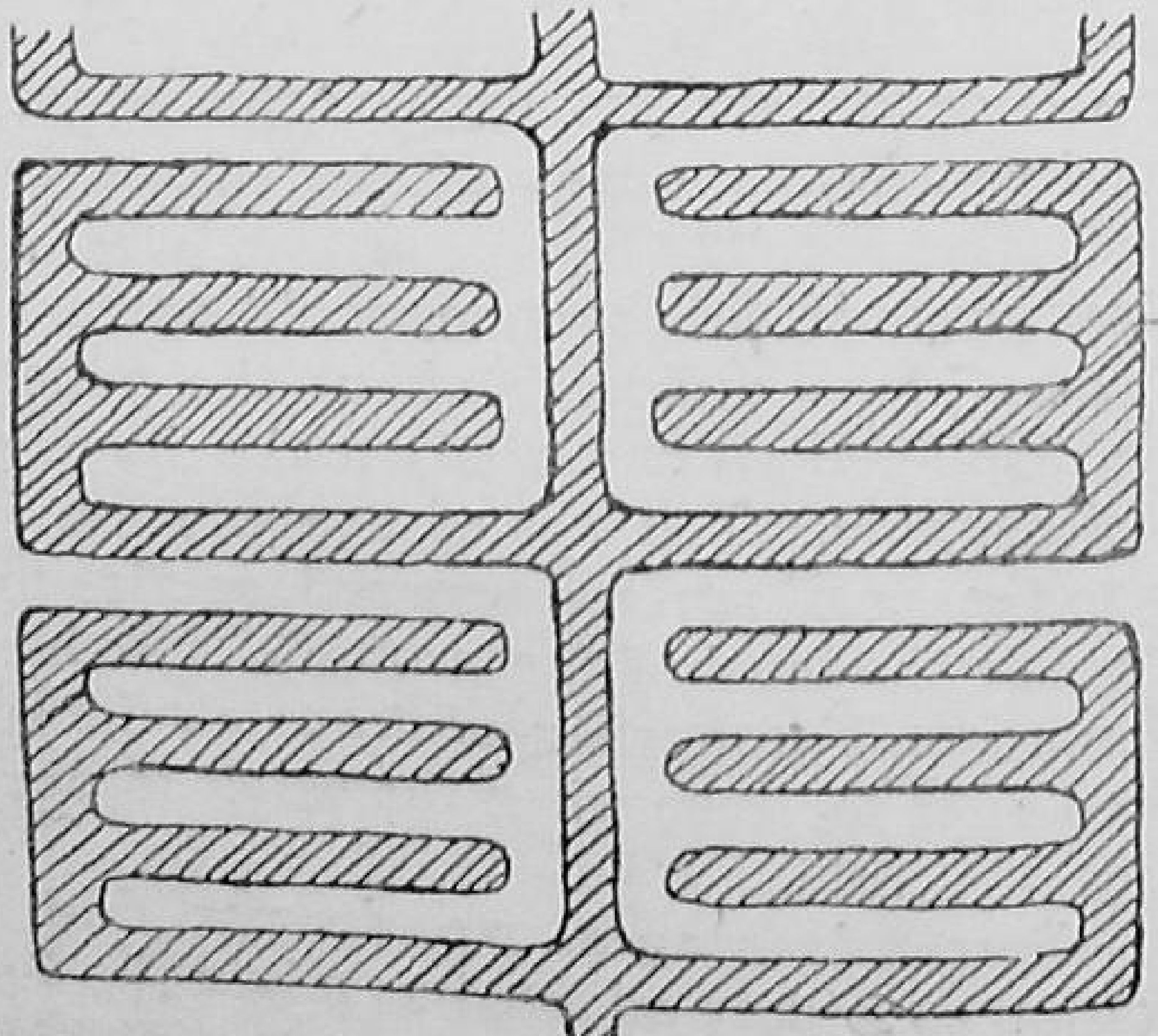


FIG. 23—Field distributary.

* Irrigation and Drainage, page 354.

The system may be seen exemplified in South India in many places, though, as noted above it is not so common as might perhaps be expected. Certain crops seem always to be watered in furrows, such as sweet potatoes, onions, and less frequently cane, while in certain districts the practice is much more common than in others. In the north of Madura for instance this system of irrigation is commonly seen. Here the farmer does away with the necessity of contours and levels by laying out the ridges and furrows as it were in small beds, into which the water is turned as in the case of flat bed irrigation. (See Fig. 23.) Transplanted crops lend themselves more readily to this method of irrigation, since the plants can be set out along the furrows ; a crop raised from seed can of course be drilled in lines at any desired distance, but if a watering is necessary to *start* the crop, flooding is undoubtedly the most convenient method to adopt.

The size and depth of the furrows and their distance apart, are matters which must be decided for each individual case, and the skill of the farmer will nowhere be more clearly shown, than in the correct adjustment of these factors. The water in the furrow percolates into the dry soil around in all directions, and as the place where the water is needed is not at the surface, but below the surface, it follows that the deeper the furrow,* consistent with good agricultural practice, the better. The distance between the furrows will mainly depend on the porosity of the soil, which governs also the rate and the distance of percolation. Sometimes the furrows are made comparatively close, and water is only let into alternate furrows at each irrigation, opportunity being taken to loosen the previously used furrows and thus by forming a soil-mulch to prevent loss from evaporation, and to increase the absorptive power of the furrows for the next watering.

Much of the success of furrow irrigation depends on the efficiency of the implements used. As has been shown, the land must first be 'graded,' i.e., brought to a uniform slope, as until this is done it is impossible to conduct the water evenly along the furrows, unless they are very short. Henderson † has described a scraper which may be utilized for this purpose, and which has the advantage of being self-tipping : it is to be used with a pair of cattle. A larger and rather better constructed pattern, called a 'buckscraper,' copied from the Journal of the Department of Agriculture, Victoria, Vol. V, p. 707, has recently been constructed, in view of Sampson's recommendations ‡ that such levellers should be used for grading the land to be acquired for the

---

* Reference may be made to the figures showing the water penetration in Furrow Irrigation in Hilgard's 'Soils.'

† Henderson : Agricultural Journal of India, Volume IV, page 395.

‡ Madras Sewage Farm : Report of Committee, 1913. Illustration sheet No. 16.

new Sewage Farm proposed for Madras. An illustration of this is given below. (See Fig. 24.)

Implements are also needed for making the furrows and can be had of various types. (See Fig. 25.) By a simple modification, the wooden country plough may be made to act as a furrow-making plough, and will work well in well-tilled lands. The sketch below (see Fig. 26) is from a Hospet plough, but even simpler additions may be made. For more thorough work, there are a number of 'double mould board' or ridging ploughs. The ridging attachments of the Planet Junior will work well in making small ridges,

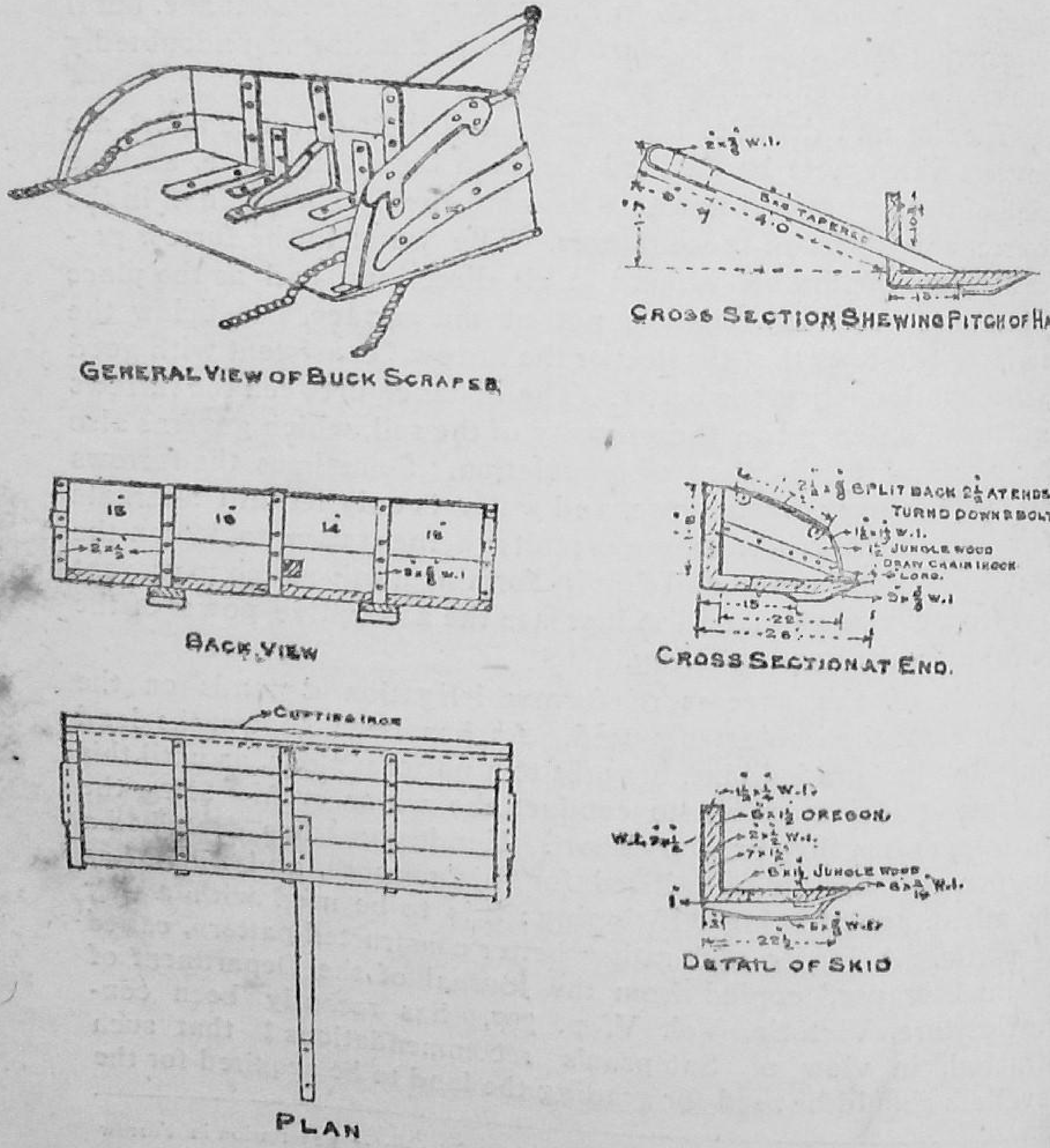


Fig. 24—A buckscraper or levelling board.

Fig. 25—Ridging land (Palur).

held up in the tank, the lands immediately beneath it tend to be waterlogged. (See Fig. 29.)

Such drains will often help to keep the lands moderately dry by lowering the water table, and thus preventing the accumulation of water on the surface. Land is often kept wet from the presence of springs, the water oozing upwards from the ground. Such springs are often very difficult to tackle, and no general rules can be laid down for their treatment. When it is not possible to intercept the excess of water which any area of land receives, arrangements must be made to remove that excess as rapidly as possible, so that

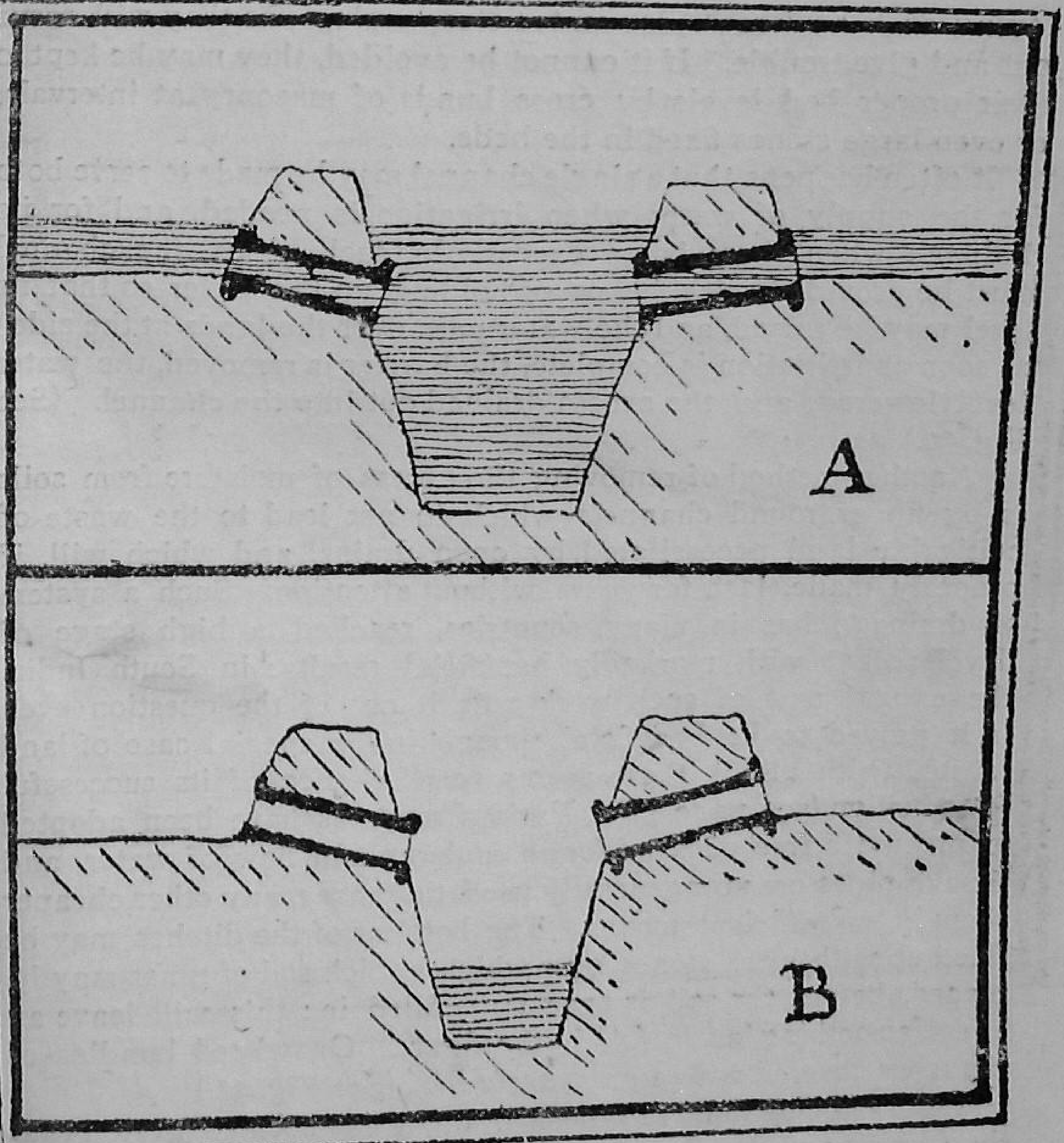


FIG. 30—Irrigation and drainage performed by the same channel. A, as irrigation channel ; B, as drain.

it may do no harm to the soil. This water may be removed over the suface or beneath the surface, and this has given rise to the two systems of *Surface Drainage* and *Underground Drainage*.

Surface Drainage is the simplest and cheapest method of dealing with excess of water. Trenches are dug at intervals over

the land, and the water soaks into these from the sides and by surface flow. If they are arranged on a slope, the water will pass along them and will ultimately be collected in a larger trench and thus removed from the land. Such drains, though at times very efficient, offer considerable hindrance to agricultural operations and need constant attention. If the sides are made steep, in order to avoid wasting more land than is necessary, they are always falling in and becoming blocked, and need constantly regrading: if the sides are made sloping, the amount of land wasted is considerable. Great care must also be taken to avoid laying such surface drains on too steep a slope, as they will scour out and give trouble. If it cannot be avoided, they may be kept to their proper bed levels by cross bunds of masonry at intervals, or even large stones fixed in the beds.

It often happens that a single channel may be made to serve both for the supply of water when irrigation is needed, and for its drainage when there is an excess. In such cases, the channel must be provided with means of holding up the water so that its level may be raised, and the water pass over the lands at the side: as soon as irrigation is complete, the barrier is removed, the water level lowered, and the excess drained out into the channel. (See Fig. 30.)

Another method of removing the excess of moisture from soils is by underground channels which do not lead to the waste of cultivable land necessitated by open drains, and which will, if properly made, last for years without attention. Such a system of drainage has in many countries, reached a high stage of development with markedly beneficial results: in South India, the capital cost of such work puts it out of the question even if it proved to be beneficial, though in the special case of land tainted with alkali, there seems some chance of its successful introduction (see page 58). Various methods have been adopted to procure a free passage for an underground flow of water, and though pipes are now generally used, there are many other cheaper though less efficient means. The bottoms of the ditches may be filled up with loose stones over which a thick sod of grass may be placed, before the soil is once more filled in: this will leave an effect something as in *(A)* in the figure. Or twisted bundles of branches covered with a grass turf *(B)*. (See Fig. 31.)

For a more permanent type of drain, it has been suggested that short lengths of bamboo, tarred to prevent decomposition, might take the place of the tiles which are commonly used when under-draining is practised. An experiment describing an attempt to reclaim a piece of alkali land in this way is noticed later (page 58) as it is only in connexion with alkalinity that such drains are likely to be used.

This practice of underdraining has, in view of its importance, accumulated a considerable literature, and the questions of the

depth of the drains, their distance apart, the best shape of tile, the most suitable gradient, the methods of forming the junctions of the tile drains, the construction of the outfalls and the technical details of laying the tiles have all received much attention, and will be found discussed at length in any European or American book on the subject.

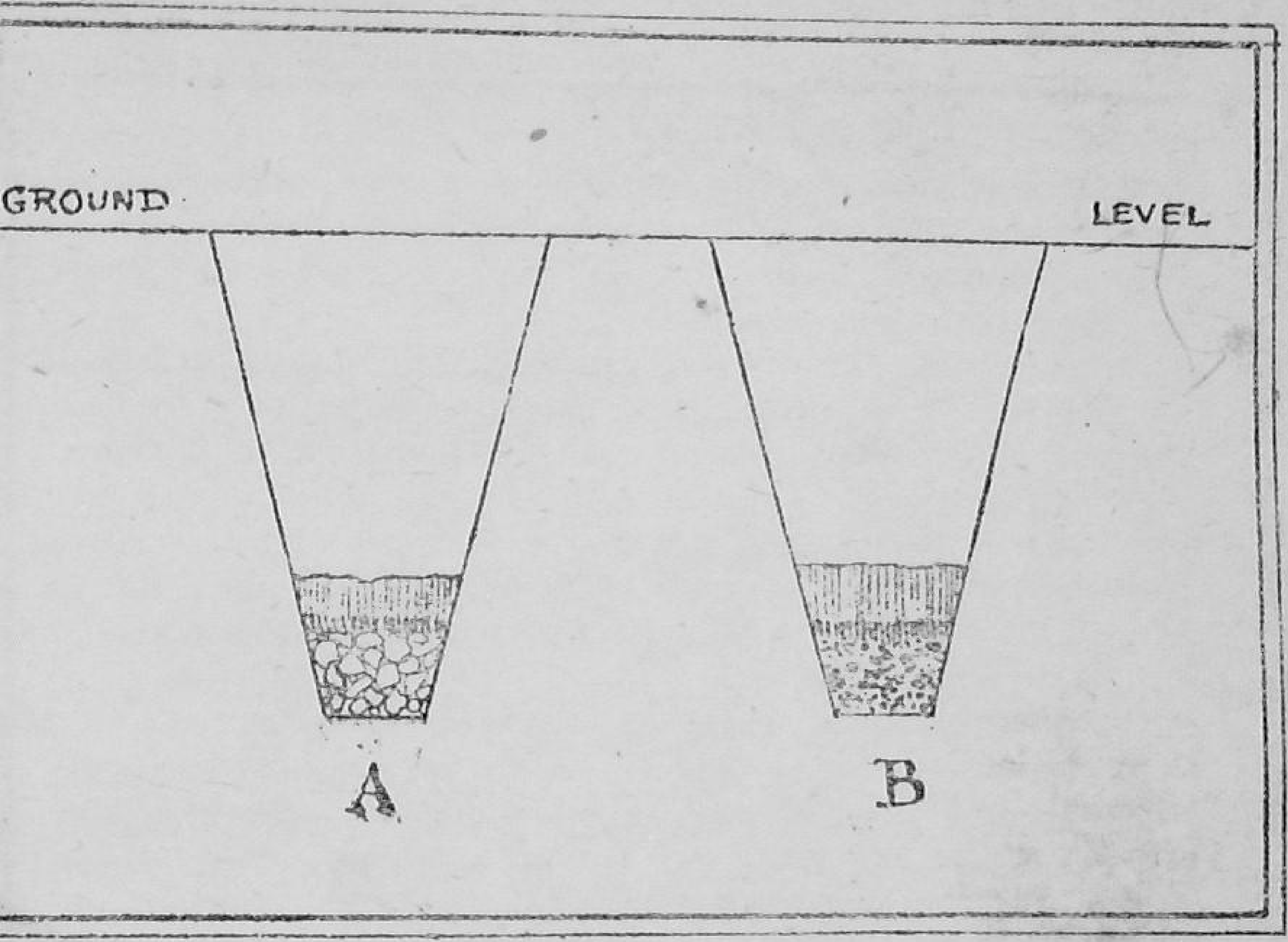


FIG. 31—Drains (A) formed by digging out trench, putting in stones and covering with turf; (B) ditto using bundles of sticks.

Mole draining is a method of underdraining land by forming open channels in the subsoil with the least possible disturbance of the soil. These channels are formed by a mole or steel cone carried at the end of a coulter which is made to pass through the ground at any depth required. As the mole plough is dragged through the ground (usually by steam power) it leaves a narrow vertical slit, with a wider opening like a rat hole below. (See Fig. 32.)

The slit quickly closes, but in stiff clayey soils the channel may remain open for some years. The interest of this system lies in the fact that it has been suggested and tried in the Punjab as a method for underdraining and reclaiming alkali lands (see page 57).

All systems of drainage whether intended to intercept the water before it reaches the land affected, or to remove the water quickly when it has got there, imply some place of discharge. This discharge will naturally be into some stream or river, since such form the natural means whereby ultimately all drainage is effected.

It is only when drainage by natural means is lacking, that man steps in to bring it about by artificial means. It may happen however that in order to work to a proper outflow, it will be necessary to consider large areas of country as a whole, when the drains will become of considerable size, and outside the reach of the ordinary individual. The assistance of the Government in such cases has been found necessary, and legislation exists in some

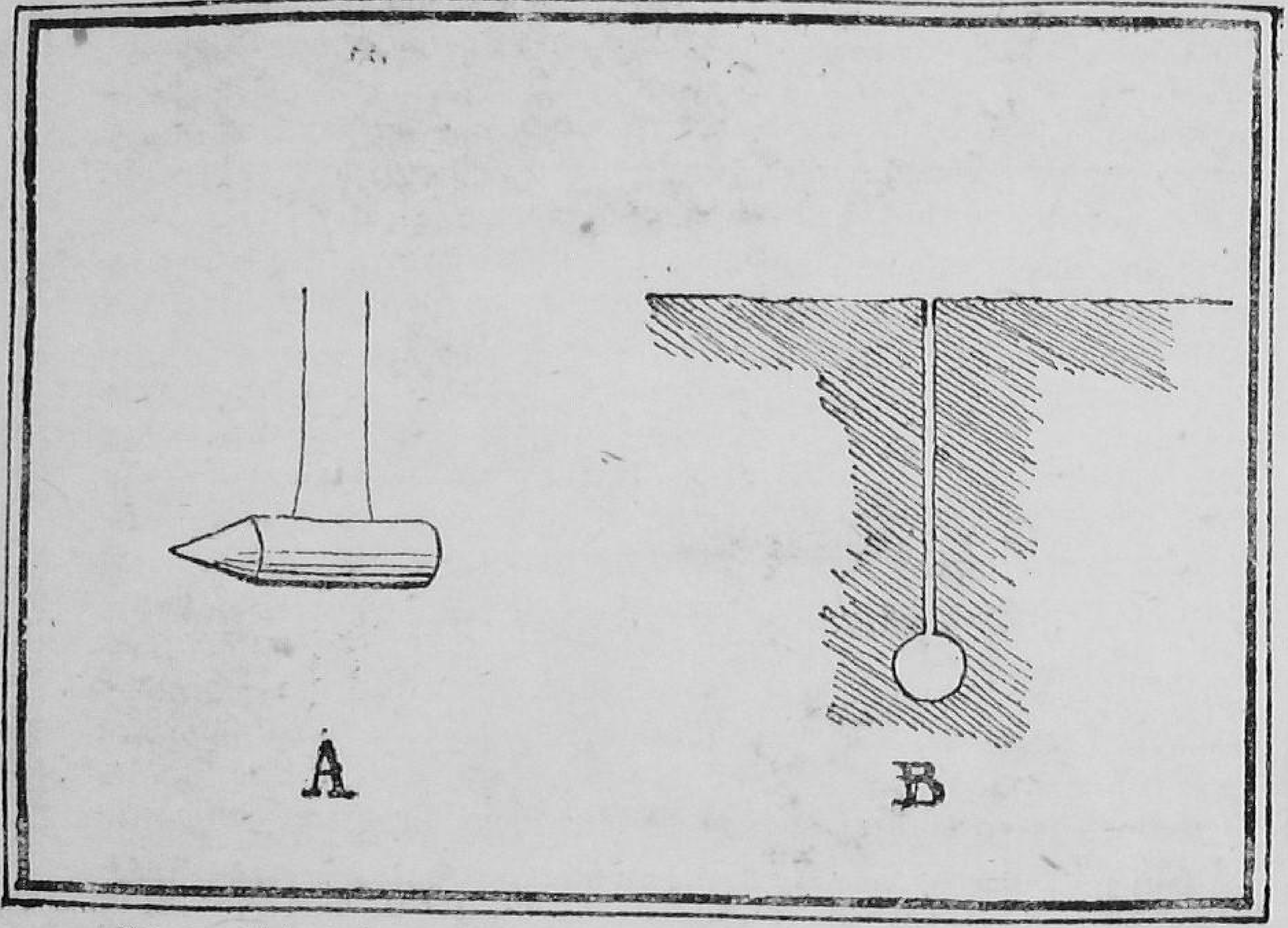


FIG. 32—Mole draining. (A) the mole, (B) diagram of the channel left in the ground by the passage of the mole.

countries enabling the necessary steps to be taken to ensure that every farmer can within reason, find an outlet for the water he wishes to remove from his land. A striking illustration of the need that may occur for such legislation, will be noticed later in the case of the saline land at Terkutteru, where it was found that the alkalinity was caused by the accumulation of the drainage of an area of several miles in extent. Though any properly constituted authority could have easily taken steps to improve matters, it was obvious that individual action was out of the question.

9. **Alkalinity.**—The problems of drainage are especially insistent in a tropical climate, because of the danger of alkalinity, which, in addition to the other evil effects of ill-drainage mentioned in the last chapter, is to be feared wherever the rate of evaporation is unduly high.

The evil effects of such alkalinity, which is brought about by a concentration of the soil solution, are twofold. Any concentrated

or less extent, is characteristic of well waters such as are used generally for garden crops; paddy cultivation is usually carried on with the aid of rain or river water, stored or diverted for the purpose.

The cause of this accumulation must be understood before any remedial measures can be suggested. The subsoil water is in a state of continual movement, sometimes upwards when evaporation at the surface is great, and when the 'pull' exerted by surface tension is towards the surface, where loss from evaporation is going on, sometimes downwards when after rainfall, the excess of water at the surface is moving slowly downward to the permanent bottom water, and so into the general drainage of the country. It follows, that in dry climates, the upward movement of the water will be increased, because not only is rainfall less abundant, but also because the rate of evaporation at the surface is proportionately greater, owing to the greater heat of the sun. *The result of an excess of upward movement over downward movement is to cause an accumulation of salt, at or near the surface*, because the salts cannot be evaporated along with the water.

Where the water table is near the surface, the rate of evaporation is obviously intensified, because the distance through which the water has to be lifted is reduced, and consequently water to replace that lost at the surface, can be more readily supplied. It is also clear that the use of irrigation water may be attended with an increase in salinity, partly because over large areas it may raise the water table with the effects noted above, and partly because any water applied at the surface, will be largely evaporated at the surface, and will increase the amount of salt in the soil by the amount which the water itself contained in solution. This is the more likely to occur if the water is sparingly applied, since heavy floodings might cause such a downward movement as would remove a portion of the salts down to the bottom water, and out of risk of further injury; light waterings which could never reach the permanent water, would be wholly evaporated at the surface and the dissolved salts left to increase the trouble. It must always be borne in mind that it is actually the *concentration* of the salts which brings about the evils described above, more than their total quantity. The diagram below (see Fig. 33) will indicate how this is brought about, and show how a partial alleviation may be obtained by distributing the salts more evenly through the soil, though it is clear that a complete cure can only be obtained by the removal of the salts from the sphere of action. Many of the methods which are adopted and adopted successfully aim at *distributing* the salts through the soil, and thus reducing their concentration, and in places where the salts are not excessive, a stationary position may be reached, where the methods of

alleviation are just sufficient to maintain the land in a state of productivity.

Not all the salts contained in the soil solution of such alkaline lands are harmful, for the same causes that bring about the accumulation of the harmful salts, also bring about the accumulation of the useful ones, as nitrates and phosphates. The salts which contribute most largely are generally harmful, and consist of sodium carbonate, and the chlorides and sulphates of magnesium

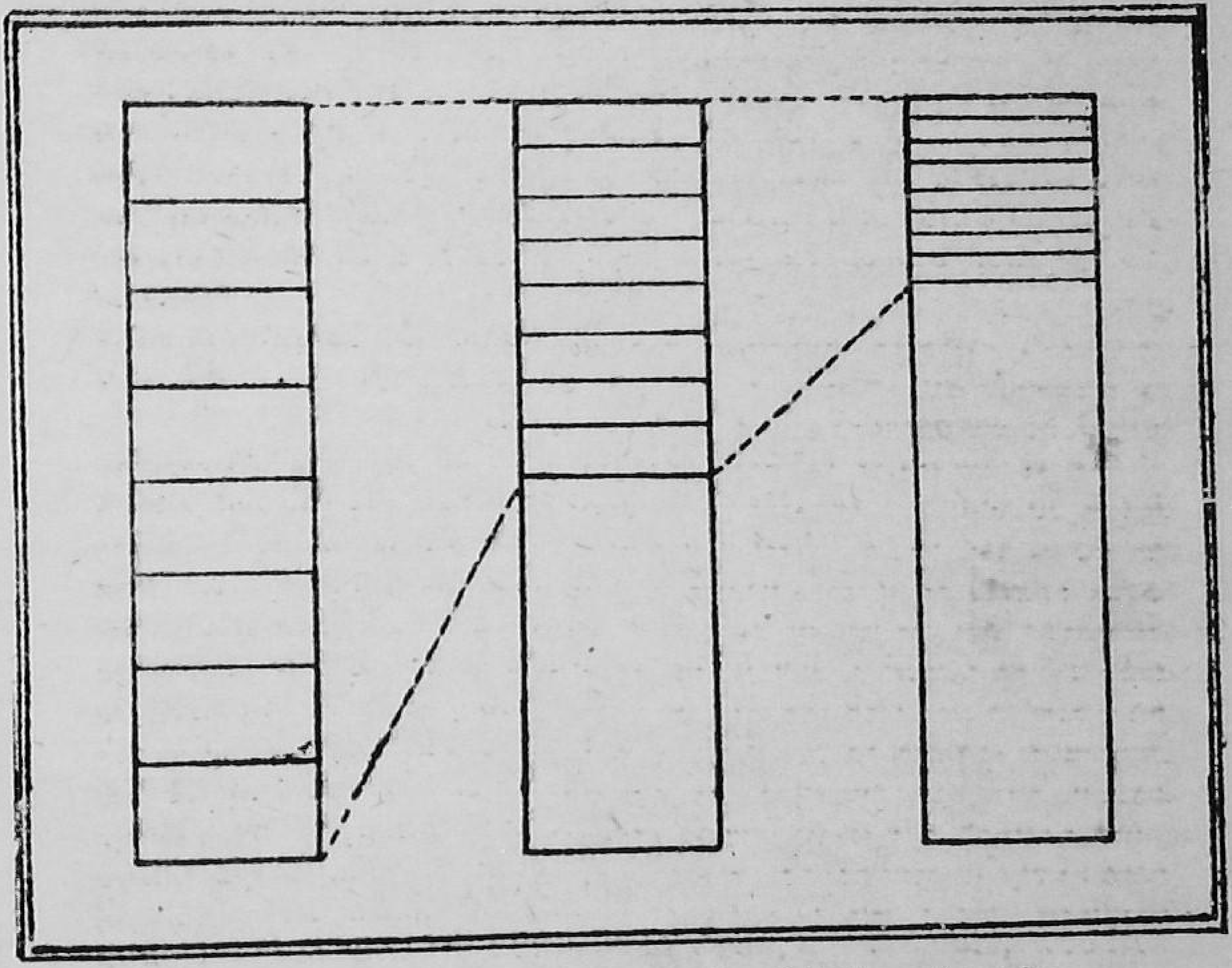


Fig. 33—Diagram to illustrate the concentration of alkali near the surface.

and sodium. Sodium carbonate is one of the worst, because of its secondary effect upon the texture of the soil; by deflocculating the clay particles, it 'puddles' the soil and makes it extremely impervious to the passage of water, thus aggravating the situation. Sodium chloride is also very generally present.

Bearing in mind that alkalinity is the result of the preponderance of the *upward* movement of the soil water over the *downward* movement, and the consequent *concentration* at the surface of the salts dissolved therein, we may see what remedial measures are adopted to prevent land becoming alkaline.

The problem is not a very serious one in the dry land of the Presidency, and where it does exist, is, as a rule, found in small isolated patches, the cause of which is generally to be traced to

underground moisture of some kind. It is a much more pressing question on any land which is irrigated, as on such lands the rate of evaporation is much increased, while the water used for irrigation may and often does, itself, contain considerable quantities of salt in solution (see page 51 supra). On garden lands, attempts at reclamation are seldom made; the aim is more to alleviate the evil and maintain a state of equilibrium. This is commonly done by improving the texture and perviousness of the soil, with heavy dressings of manure or silt. One of the most marked effects of alkali is to render the soil close and sticky, and thus aggravate the conditions which originally were the cause of its appearance. The use of bulky organic manures, such as farmyard manure, or town rubbish counteracts this, and by keeping the soil open, enables the water to pass through; even if it does not reach the bottom water, it is at any rate diffused more widely through the soil, and the risk of concentration avoided. A similar effect, though not so obvious, is the use of tank silt in large, sometimes very large, quantities; the effect again is to keep the soil open. Methods of cultivation are sometimes adopted in wet lands cropped under garden conditions which seem to indicate a realization of the risk of alkali, and its prevention by suitable methods; a striking instance of this is the very careful drainage given to plantain topes, in the wet lands in the Cauvery valley; attention, often insufficient, is also given to the drainage of sugarcane fields in wet land.

Wet cultivation, i.e., the growing of swam paddy stands on rather a different footing; the maintenance of standing water on the surface of the soil means that no upward movement is possible, and provided water is abundant, little trouble is in general experienced with alkalinity. It is only where the water is itself charged with salts, the land is affected by the proximity of the sea, or the water-supply is scanty, that trouble is likely to arise. In such cases alleviation is preferred to cure; and the remedy is similar to those already mentioned. Large quantities of leaf or other organic matter—in parts of the Kistna, they only cut half the straw, leaving the other half to be trampled into the field—are incorporated with the soil.

To effect the same purpose, i.e., to improve the permeability of the soil, a recommendation has been made to use *Gypsum* (Calcium Sulphate). This is for soils where sodium Carbonate is present as the main source of trouble; a chemical action takes place between these two salts which results in the formation of Calcium Carbonate and Sodium Sulphate, the latter a comparatively innocuous substance. This method of treating such soils is referred to in "Investigations on Usar land in the United Provinces" by J. W. Leather,* where it is reported to have been successful, though the

* Allahabad, 1914, published by the Government Press, Allahabad.

cost was prohibitive (the gypsum cost Rs. 20 a ton, and the dressing necessary from Rs. 700 to Rs. 800 an acre).

The practice of careful mulching will, by reducing the amount of evaporation at the surface, reduce the upward movement of the water, but this is nowhere so far as the writer is aware, *definitely* practised for this purpose. It is a matter of observation, that lands when they are once allowed to go out of cultivation, rapidly deteriorate.

Other remedies which have been suggested, and indeed put into practice, are to scrape off the salt incrustation and the first inch or two of soil charged with salt, and remove it. An experiment at Gursikran in the United Provinces by J. W. Leather, where the salts were thus scraped off the surface regularly twice a year, was found, after eight years, a complete failure.* It is suggested that digging out the whole of the top salt-impregnated soil, up to a depth of four feet if necessary, might prove not only successful but profitable. The disposal of the soil thus removed does not appear to have been considered: if the practice became at all common, it would present some difficulty. Yet again a temporary improvement might follow by the thorough inversion of the soil which would be an improvement, until the salts worked up again.†

Though all the remedies treated above are in certain conditions successful in *maintaining* the fertility of lands more or less impregnated with salts, it is clear that they cannot be considered efficient, as they do not remove the cause of the trouble, but merely mask its effect. The only remedy for such lands is *drainage*, as by drainage only can the salts effectually be removed. In temperate climates, when the evaporation caused by the heat of the sun is less, and when the rainfall is greater, alkalinity does not occur a heavy rainfall, in conjunction with a porous soil, keeps the West Coast submontane area free from alkalinity, nor is such found in the plantations and estates maintained at considerable elevations on the hills of Southern India. If the natural drainage is bad, it must be improved; if the rainfall is insufficient, irrigation water must be utilized to increase the downward movement of the water through the soil. Drainage may be combined with other remedies to increase the perviousness of the soil, and crops selected which even before reclamation is complete, will bring in some return, and aid in the process, but ultimately, the leaching out of the salts and their removal by some system of drainage, lies at the root of every permanent cure.

The simplest method of doing this is by flooding, i.e., covering the surface with a copious supply of water and allowing it to drain away bearing the salts with it. This is what happens in the

* Allahabad, 1914, published by the Government Press, Allahabad.
† Hilgard: "Soils," page 456.

cultivation of swamp paddy, the removal of the salt solution being effected partly over the surface and partly underground. It will be shown later that the cultivation of swamp rice, is often the only feasible way of making use of irrigation water without the risk of spoiling the land. The quantity of water must be adequate, or the remedy will fail, and may even do a great deal of damage to the land by increasing the evaporation. Under the old system of basin irrigation in Egypt, the land was thoroughly washed for fifty days a year and was kept sweet : the perennial system of watering which has replaced it, implies as many as twenty waterings in a year with a total depth of seven feet; the moisture never sinks much more than two feet into the soil and is then evaporated. In these conditions the increase in alkaline lands is not surprising, since special precautions in the way of allowing for the removal of the drainage water have not, until recently, been taken.

The process of 'washing' which has to be adopted to free lands which have been spoilt by such injurious accumulation of salt, is well described in the Text-book of Egyptian Agriculture (Foaden and Fletcher, Volume I, page 201) where the necessity of forcing the water *through* the soil is emphasized: merely letting the water in at one end and out at the other, is shown to be wasteful and unsatisfactory.*

Egyptian experience has also been utilized in the reclamation work carried on by Henderson in Sind, and fully described in Bulletin No. 64 of 1914 of the Bombay Department of Agriculture. There is a considerable quantity of kalar land in Sind, which, at present, owing to the scarcity of the population, the insufficiency of the water-supply, and the habit of fallowing the land, is not very serious: there is, at present, sufficient good land to utilize all the water available. There is a prospect however of an increase in the number of perennial canals, and this will mean that some kind of rotation will have to be adopted in order to obtain a return for the water. The system adopted by Henderson, was to get rid of the salt by washing it down into the subsoil, and then grade up the soil by growing repeated crops of 'berseem' (*Trifolium alexandrium* : Egyptian white clover). The usual rate allowed under the canal rules to this land was 1 cusec to 300 acres, which allowed only one-third of the gross area to be irrigated in any season. This proved quite insufficient for reclamation work, and Henderson calculates that for thorough washing, a duty of 25 would have to be allowed.†

The reclamation has proved entirely successful; for various reasons beyond the control of the experimenter, it has not actually

---

* See also "Reclamation of alkali lands in Egypt." Thos. H. Means. U.S.A. Bulletin No. 21.

† The details of the scheme, the method of levelling and dividing up the land are given in detail in the bulletin referred to, which may be consulted.

proved a financial success, but it is clear, from the figures published, that such reclamation will ultimately pay, and in fact the farm at Daulatpore made a handsome profit during its last year before it was sold.

A serious increase in the amount of alkalinity has attracted considerable notice in the irrigated colonies of the Punjab, and it is of interest to see what recommendations have been made. The general causes assigned for the increase were four: the dry climate, the general lack of contour which exhibited little natural drainage, the *sandy* soil of comparatively recent origin, and lastly the newly-added effect of irrigation. The water has increased the amount of chemical action, and thus increased the amount of salts to be reckoned with, and the continual effect of irrigation has raised the subsoil water enormously, mainly through seepage from canals made in such porous soils. In the Chenab colony, this rise is reckoned at the rate of two feet every year. This has again increased the risk of salt by increasing the rate of evaporation. It is clear that the soil must in some way be washed, but with the water table so high, it is not feasible to force the salts down into the subsoil and they must be completely removed. This it is proposed to effect by the use of a mole plough, such as has been already described.

The water is run into an open drain and thence into a puddled tank where it will evaporate (this process will be accelerated if necessary by pumping it over suitable structures): the salts thus obtained will, it is hoped, form a considerable asset in reckoning up the cost of the scheme. The cost of this scheme, which has been evolved by Barnes of the Punjab Department is calculated to be Rs. 10 an acre; the tackle will cost Rs. 22,000: and will do seven acres a day with drains eight yards apart; allowing 40 per cent of time taken in moving it about, it should do over 1,000 acres a year.

Besides the above, very costly trials have also been made in cementing the canals to make them water-tight, at a cost of over a lakh a mile.

An experiment on a small scale may be referred to here, which was carried out on some slightly alkaline wet land on the Central Farm, Coimbatore, designed to ascertain the cost and efficiency of underdrainage as a means of reclaiming land. The experiment has been fully reported in the Agricultural Journal (Volume IX, page 295) to which reference may be made. The experiment has shown that there is no difficulty in laying down such subsoil drains, but their effect on really bad alkaline land has yet to be proved, though it is hoped to test this aspect of the question before long. The most serious trouble will probably be found in arranging for a sufficient slope to the drains and an outfall for the drainage water they remove, since it is in those places where

natural drainage is bad, and where the subsoil water is high, that such cases will be found.

In this connexion, it may be emphasized that individual efforts are in many cases not to be thought of, and that only concerted effort is likely to be successful.

Some experiments were carried out for some years at the village of Terkutteru near Madura, where various remedies were tried. It was ultimately found that the village lay in a shallow depression, the land sloping gently upwards in all directions, for a considerable distance, and the true remedy was the construction of a proper system of drainage extending over the whole of the area concerned, one of several square miles. This is a case in point, where the individual was helpless, and the intervention of the State was indicated.

Lastly it has been said that the planting of trees in alkaline lands may be attended with success, and that the trees will gradually pump the water out, and by lowering the water-table, diminish the causes which have given rise to the alkalinity. It is true, for instance, on the hills, that the planting of *Eucalyptus* is considered a simple remedy for the amelioration of swampy land, but salts are absent, and it may be doubted whether much can be effected in this way. The experiment has been tried in the United Provinces, but has not proved successful.* *Butea frondosa* trees were planted in pits, carried through the salt layer to the coarser sand below, and filled at the time of planting with a mixture of sand and manure. The trees grew and gave a profitable return for this class of land, but Leather shows that they have no effect in reclaiming the land (*loc. cit.*, p. 49). Babul also gave a return : mango proved a complete failure.

As has been pointed out above, the general position in Madras is not very serious, in that there are no large stretches of alkali land calling for reclamation. Alkalinity occurs sporadically, sometimes on dry lands, more often on wet lands. On garden lands conditions vary, but where the water is of an alkaline nature, and the soil naturally impervious, the dread of alkalinity is never far from the mind of the ryot. He is usually able with the resources at his disposal to keep it down, though it undoubtedly causes great reduction in the yield and perhaps more markedly in the quality of his produce. A more extended use of green-soiling and the use of an inverting plough would be good practice. It is also generally known that certain crops are able to resist quantities of salt in the soil which would be fatal to others. In Hilgard's " Soils " several pages are devoted to a thorough comparison of the differing powers of resistance possessed by many field crops, based on much careful experiment, but such knowledge is not yet available in this country.

---

* Cawnpore Agricultural Station Reports, 1909, and subsequent : Tulli Usar Sub-Station.

Ragi and tobacco are two crops which do not seem to suffer much, while wheat grown at a drier portion of the year fails to produce a full berry on land but slightly tainted. The question is one of great interest, because in any scheme of reclamation the sooner a crop can be taken the less will be the cost of the operation. In this connexion, the use of a coarse red rice, or on still poorer lands 'dineba' (*Panicum Omogali*)* in Egypt may be noted: they are used partly as indicators to estimate the amount of salt still present, and partly to bring in some return during the process of reclamation.

On wet lands, except when the drainage is especially bad, or when the water-supply is insufficient, alkalinity is not common. The system of cultivation adopted, in itself tends to remove the salt formed, since water is kept standing at the surface and thus the downward movement is accentuated. So it is that except in very unfavourable circumstances such land is not found. A notable exception is the increasing area of alkaline land to be found in the area irrigated by the waters of the Periyar in the Madura district: allusions have been made above to the experiments conducted there. Much of the trouble is caused by insufficient attention to drainage, which has brought the water table too close to the surface, or which has kept the lands moist during the dry weather and thus increase the quantity of water evaporated at the surface. The state of affairs is aggravated by the necessity for manure and the difficulty of obtaining it; unlike the other large paddy growing systems of Madras, the land is not of an alluvial character nor is any silt received in the water.

From this aspect then, the cultivation of swamp paddy has reason behind it, and though at first sight it seems wrong that water should be used as liberally as the system demands,† when by its judicious use for the ordinary dry crops, it could be made to go much further and perform a higher duty, there are strong grounds for believing that the system is the result of experience, and is indeed not only the most desirable but often the only possible system.

The matter has attracted some attention, and quite recently an experiment was carried out under a newly constructed tank, to test the possibility of using such water for the purpose of irrigating dry crops, i.e., for garden cultivation. The experiment ended in failure, but there is much to be learnt from it.

---

* U.S.A. Bulletin No. 21, page 28.

† Saidapet Farm Records, page 142. "It is popularly generally believed that the amount of water generally used for irrigating the crop is far in excess of its actual requirements—it monopolises water which might be far more usefully employed for irrigating maize, wheat or other crops which might be grown with a little of the water now used for paddy—and yet the extension of irrigation works on the old system goes on."

The site of the experiment was Ponnalur, a village in the north of the Nellore district: the tank was originally designed to water 1,000 acres, partly red soil and partly black *regada* lands. A prohibitive water-rate of Rs. 20 an acre was charged for paddy, water for any other crop being allowed free. This was in 1904; the concession was originally for three years, but was extended. During this time there was a failure of the ordinary rains, but in spite of this, the people for the most part obstinately refused to use the water. A certain amount of ragi was irrigated, but the general opinion was that using water in this way would spoil the land by rendering it salt and unfit for further cultivation. In 1909 the idea was given up, and the use of water for swamp paddy has gradually been taken advantage of by the people of the village. There is still (fasli 1324) a certain amount of irrigated dry crop, 136 to 290 acres of paddy, but there was a large area of the same dry crops grown dry, which shows that even now the water is not fully utilized. This is not wholly due to disinclination, it is true, for there are certain difficulties in arranging for channels passing over other people's property. It is very significant that a deficiency of manure is felt: in fact it is practically true that this limits the area which might be brought permanently under garden cultivation.

There is no doubt that the land has suffered where water has been used for irrigation (dry crops) as opposed to swamping (paddy), and there is also distinct evidence to show that some of the lands marked in fasli 1320 as hopeless, have been improved by growing paddy on them. The evidence here seems clear, but it is of course not possible to say how far Ponnalur experience would be repeated elsewhere. Salt was present to a considerable extent as shown by analysis, mostly in the form of Sodium Chloride, and the effects were almost instantaneous: it may be presumed that they would be similar elsewhere, though perhaps not so rapid.

It may be said that such water might be stored against a season of draught, when it might be used to save a wide area of dry crops from destruction, but a little reflection will show that this is not feasible. Firstly in a dry year, i.e., a year of short rainfall, when the demand would be the highest, the supply, which ultimately depends on the rainfall, would probably be at its lowest: and it would not be possible to meet all demands. The loss in seepage in running water down new and unsettled channels would be very high, and the financial arrangements would be difficult to settle. A system of insurance, i.e., a fixed sum to be paid yearly whether water was wanted or not would certainly lead to trouble and waste of water, while if the ryot was only to pay when water was used, he would not ask for it until the very last minute, when everyone would be clamouring for water at once. The demand for water must be a regular one, in order that the project

shall pay, and this can only be obtained by paddy cultivation or the introduction of regular garden (i.e., intensive) cultivation. This means the most skilful tillage combined with liberal manuring, with marketing conveniences at hand, and such conditions are by no means universal or indeed easy to find.

It is therefore probable that in the conditions obtaining in the Presidency, the cultivation of swamp paddy is the best method of using stored water, and that the universal adoption of this crop, and the strong desire shown to grow it wherever possible are based on past experience. Allusion has been made to the trouble caused in Egypt, by the substitution of one form of irrigation for another, while it may even be that the cause of the many abandoned ancient irrigation systems is to be found in the accumulation of harmful alkali salts, due to the careless use of the water supplied.

IRRIGATION AND DRAINAGE.

Books to be read by students.

Number.	Name of author.	Name of publication.	Nature of publication.
1	Chatterton	Life Irrigation.	
2	Harrison	The methods of reclaiming saline soils.	Madras Agricultural Leaflet No. 1 of 1912.
3	Hilgard	The soil.	
4	Hilgard and Loughbridge.	Alkali Lands : Nature, value and utilization, and tolerance of Alkali by cultures.	California Bulletin No. 128 and 133. Reprinted 1906.
5	King	Irrigation and Drainage.	
6	Krishnamurti Rao ...	Salt in well water	M.A.S.U. Jl., Vol. II, p. 15 seq.
7	Mackenzie	Notes on Irrigation works.	
8	Mehta	Experiments with water finder ...	Bombay Agricultural Bulletin No. 38.
		FURTHER READING.	
1	Dybowski	Traite Pratiquede Cultures Tropicales, 1902.	
2	King	Physics of Agriculture.	
3	Leather	Reclamation of Reh or Usar land.	Agricultural Ledger, 1897, No. 7.
4	Markham	Report on the Irrigation of Eastern Spain.	
5	Risler and Wery	Irrigations et Drainages.	
6	Roth	Notes on Continental Irrigation.	
7	Smith, R. B.	Italian Irrigation.	
8	Widtsoe	The principles of Irrigation Practice.	
9	Wilcox	Irrigation farming.	
10	Wilcocks, Sir W. ...	The Irrigation of Mesopotamia.	
		U.S. DEPARTMENT OF AGRICULTURE—BULLETINS.	
11	Bond and Keeney ...	Irrigation of Rice in the United States.	Office of Experimental Station: Bulletin No. 113.
12	Fortier	Evaporation losses in Irrigation and water requirements of crops.	Office of Experimental Station: Bulletin No. 177.
13	Johnston	Egyptian Irrigation	Office of Experimental Station: Bulletin No. 130.
14	Loughbridge	Distribution of water in the soil in Furrow Irrigation.	Office of Experimental Station: Bulletin No. 203.
15	Mead and Johnston ...	The use of water Irrigation ...	Office of Experimental Station: Bulleti
16	Means	Reclamation of Alkali lands in Egypt.	Bureau Bulleti
17	Tait	The use of underground water for Irrigation at Pomona, California.	Office o mental Bulleti

PRINTED IN INDIA BY THE MANAGER, GOVERNMENT OF IND.
PRESS, FARIDABAD, 1962